Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

Canada

91-01219/

RESEARCH ON BOG PREPARATION AND PEAT SOD DRYING TECHNIQUES IN NEWFOUNDLAND (1986-1988)

PREPARED FOR:

Efficiency and Alternative Energy Technology Branch
Energy, Mines and Resources Canada
Ottawa, Ont.
DSS Contract No. 51SZ.23216-6-6098
and
Energy Program Division
Department of Mines and Energy
Government of Newfoundland and Labrador
January 31, 1989

PREPARED BY:

Northland Associates Ltd.
P.O. Box 1734
42 Power's Court
St. John's, Nfld.
A1C 5P5

SCIENTIFIC AUTHORITIES:

Jody Barclay
Bill Reynen
Cecile Granger
Efficiency and Alternative Energy Technology Branch
Energy, Mines and Resources Canada
580 Booth Street, Ottawa, Ont. K1A 0E4

MICROMEDIA

CITATION

Northland Associates Ltd. Research on Bog Preparation and Peat Sod Dry Techniques in Newfoundland (1986-1988). Report of Contract File 51SZ.23216-6-6098. Efficiency and Alternative Energy Technology Branch, Energy, Mines and Resources Canada, Ottawa, Ontario. 1989 (168 pp.)

Copies of this report may be obtained through the following:

Efficiency and Alternative Energy Technology Branch
Energy, Mines and Resources Canada
580 Booth Street, 7th Floor
Ottawa, Ont.
K1A 0E4

or

Interlibrary Loans
CISTI Library
National Research Council
Bldg. M-55, Montreal Road
Ottawa, Ont.
K1A 0S2

DISCLAIMER

This report is distributed for informational purposes only and does not necessarily reflect the views of the Government of Canada nor constitute an endorsement of any commercial product or person. Neither Canada nor its ministers, officers, employees or agents makes any warranty in respect of this report or assumes any liability arising out of this report.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Jonathon Price, Dr. Arvid Landva, Livain Michaud, Kevin White and the Monenco Peat Group for their contributions to the project and final report. Thanks also go to Dr. Ralph Overend, Bill Reynen, Cecile Granger and John Drover for their advice and guidance during the past three years.

c Minister of Supply & Services Canada 1989
Catalogue No. M91-7/62-1989E
ISBN. 0-662-17333-3

ABSTRACT

The peat deposits in Newfoundland have the potential to supply a portion of the island's energy needs, especially in the areas of the province where there is no other viable biomass supply. However, this potential remains under-utilized due to drainage problems as well as poor natural drying conditions. As a result, a three-year project with the following major objectives began in 1986:

- to evaluate modified drainage systems (5, 10 and 20-meter ditched fields) through a series of field trials
- to evaluate the effects of the various drainage methods on the drying cycle of peat sods
- to evaluate the effect of rainfall over time on the water table levels and the moisture content of the *in situ* peat of the various width fields

Two different sites were chosen for the drainage trials: a blanket bog on the southern Avalon Peninsula; and a slope bog complex in the central region of the Avalon. The peat stratigraphy is quite different at the two sites and provides interesting comparisons of the drainage characteristics of the different peat types.

RÉSUMÉ

Les dépôts de tourbe de Terre-Neuve pourraient répondre en partie aux besoins d'énergie de l'île, particulièrement dans les régions de la province où il n'existe aucune autre source viable biomasse. Toutefois, ce potentiel reste sous-utilisé en raison de problèmes de drainage et de mauvaises conditions naturelles de séchage. On a entrepris en 1986 un projet triennal dont les principaux objectifs sont les suivants:

- évaluation d'une série d'essais sur le terrain portant sur des systèmes de drainage modifies (champs de 5, 10 et 20 mètres de large avec fossés)
- évaluation des effets des diverses méthodes de drainage sur le cycle de séchage des mottes de tourbe
- évaluation de l'effet des pluies en fonction du temps sur les niveaux de la nappe phréatique et de la teneur en humidite de la tourbe provenant de champs de diverses largeurs

Deux sites différents on été choisis pour les essais de drainage: le premier était un sol tourbeaux situé dans le sud de la presqu'île Avalon; le deuxième, un complexe tourbeaux en pente situé dans le région centrale de la presqu'île Avalon. La stratigraphie de la tourbe est assez différente aux deux endroits, ce qui permet des comparisons intéressantes des caractéristiques de drainage de différents types de tourbe. L'analyse des données est en cours.

TABLE OF CONTENTS

		Page
Acknowledgements		i
Abstract		iii
Table of Contents		v
List of Figures		vii
List of Tables		ix
EXECUTIVE SUMMARY		1
1.0 INTRODUCTION		5
1.1	Background	5
1.2	Objectives	6
1.3	Report Format	6
2.0 SITE DESCRIPTION		9
2.1	General Description of the Blanket Bogs of Southeastern Newfoundland	9
2.2	St. Shotts Site	11
2.2.1	Peat Stratigraphy	11
2.3	Markland Site	18
2.3.1	Peat Stratigraphy	18
3.0 MONITORING PROGRAM - PART A		25
3.1	Climatic Data	25
3.1.1	Precipitation	26
3.1.2	Fog	26
3.1.3	Sunshine, Wind Speed and Air Temperature	26
3.1.4	Summary	30
3.2	Sod Peat Drying Monitoring Activities	30
3.2.1	Objectives	30
3.2.2	Description of Cutting Methods	30
3.2.3	Methodology for Moisture Content Determination	32
3.2.4	Results and Discussions	32

4.0 MONITORING PROGRAM - PART B 39

4.1 Introduction 39
4.2 Moisture Content of the Surface Peat Layer 40
4.2.1 In situ Peat Moisture Content Monitoring Program 40
4.2.2 Results and Discussions of the In situ Peat Moisture Contents 40
4.3 Water Table Draw Down — Introduction 56
4.3.1 Water Table Monitoring Program - Methodology 56
4.3.2 Results and Discussions of the Water Table Changes 56
4.3.2.1 Water Table Changes 57
4.3.3 Peatland Drainage Models for St. Shotts 58
4.3.4 Conclusions 77

5.0 ECONOMIC EFFECTS OF VARIOUS DRAINAGE PATTERNS ON PEATLAND DEVELOPMENT 79

5.1 Analysis 81
5.1.1 Results of the Analysis 82
5.1.2 Interest Rate 82
5.1.3 Escalation Rate 82
5.1.4 Perimeter Ditch Costs 82
5.1.5 Field Ditching Costs 82
5.1.6 Initial Surveying and Layout 86
5.1.7 Field Maintenance 86
5.2 Conclusions 86

6.0 CONCLUSIONS AND RECOMMENDATIONS 87

6.1 Conclusions 87
6.2 Recommendations 88
6.2.1 Study Proposal for 1989 88

7.0 REFERENCES 91

APPENDIX 1

Geotechnical Investigations of Peatlands at St. Shotts and Markland, Newfoundland 95

APPENDIX 2

St. Shotts' Peatland Drainage Project 145

LIST OF FIGURES

Figure 1	Location Map	10
Figure 2	St. Shotts Study Site	12
Figure 3a	Peat Profiles, A-Line, St. Shotts	15
Figure 3b	Peat Profiles, B-Line, St. Shotts	16
Figure 3c	Peat Profiles, C-Line, St. Shotts	17
Figure 4	Markland Study Site	20
Figure 5a	Peat Profiles, A-Line, Markland	21
Figure 5b	Peat Profiles, B-Line, Markland	22
Figure 5c	Peat Profiles, C-Line, Markland	23
Figure 6	Comparison of Yearly Rainfall - St. Shotts	27
Figure 7	Average Rainfall - May to September	28
Figure 8	Layout of Peat Fields at St. Shotts	31
Figure 9	Moisture Content of Super Cutter and Field Press - 1987	34
Figure 10	Weekly Water Loss - Super Cutter and Field Press - 1988	35
Figure 11	Moisture Content of Super Cutter and Field Press - 1988	36
Figure 12	Weekly Water Loss - Super Cutter and Field Press - 1988	37
Figure 13a	% M.C. 0-10, 10-20, 20-30 cm layers - 5 meter field (1987)	42
Figure 13b	% M.C. 0-10, 10-20, 20-30 cm layers - 10 meter field (1987)	43
Figure 13c	% M.C. 0-10, 10-20, 20-30 cm layers - 20 meter field (1987)	44
Figure 14	% M.C. 5, 10, 20 meter fields, 0-30 cm layers (1987)	45
Figure 15a	% M.C. 0-10, 10-20, 20-30 cm layers - 5 meter field (1988)	46
Figure 15b	% M.C. 0-10, 10-20, 20-30 cm layers - 10 meter field (1988)	47
Figure 15c	% M.C. 0-10, 10-20, 20-30 cm layers - 20 meter field (1988)	48
Figure 16	% M.C. 5, 10, 20 meter fields, 0-30 cm layers (1988)	49
Figure 17	% M.C. 5, 10, 20 meter fields, 20-30 cm layers (1987)	50
Figure 18	% M.C. 5, 10, 20 meter fields, 20-30 cm layers (1988)	51
Figure 19a	% M.C. 0-10, 10-20, 20-30 cm layers - 5 meter field (1988)	52

Figure 19b	% M.C. 0-10, 10-20, 20-30 cm layers - 10 meter field (1988)	53
Figure 19c	% M.C. 0-10, 10-20, 20-30 cm layers - 20 meter field (1988)	54
Figure 20	% M.C. 5, 10, 20 meter fields, 0-30 cm layers (1988)	55
Figure 21a	Daily water table levels on a 5 meter field (St. Shotts, 1987)	59
Figure 21b	Daily water table levels on a 10 meter field (St. Shotts, 1987)	60
Figure 21c	Daily water table levels on a 20 meter field (St. Shotts, 1987)	61
Figure 22	Daily water table levels on all fields (St. Shotts, 1987)	62
Figure 23	Lateral water table profile on a wet and dry day (St. Shotts, 1987)	63
Figure 24	Lateral water table profile on a wet and dry day (St. Shotts, 1988)	64
Figure 25	Lateral water table profile on a wet and dry day (Markland, 1988)	65
Figure 26a	Daily water table levels on a 5 meter field (St. Shotts, 1988)	66
Figure 26b	Daily water table levels on a 10 meter field (St. Shotts, 1988)	67
Figure 26c	Daily water table levels on a 20 meter field (St. Shotts, 1988)	68
Figure 27	Daily water table levels on all fields (St. Shotts, 1988)	69
Figure 28a	Daily water table levels on a 5 meter field (Markland, 1988)	70
Figure 28b	Daily water table levels on a 10 meter field (Markland, 1988)	71
Figure 28c	Daily water table levels on a 20 meter field (Markland, 1988)	72
Figure 29	Daily water table levels on all fields (Markland, 1988)	73
Figure 30a, 30b and 30c		74-76

Predicted equilibrium water table (curved line) at a 5, 10 and 20 m drainage site, based on Ivanov's (1975) model. The lower axis represents the contact between mineral soil and peat, and the horizontal line is the actual peat surface. Only the 5 m site has a predicted equilibrium water table which is all below the surface.

Figure 31	Sensitivity Analyses Interest Rate	83
Figure 32	Sensitivity Analyses Escalation Rate	83
Figure 33	Sensitivity Analyses Perimeter Ditch Cost	84
Figure 34	Sensitivity Analyses Field Ditch Cost	84
Figure 35	Sensitivity Analyses Surveying and Layout	85
Figure 36	Sensitivity Analyses Ditch Maintenance Costs	85

LIST OF TABLES

Table 1	Hours of Sunshine - June to September, St. Shotts	29
Table 2	Variation in Gross Area Requirement for a 200 Hectare Production Site	80
Table 3	Estimated Perimeter Ditching Requirements for a 200 Hectare Production Site	80
Table 4	Estimated Field Ditching Requirements for a 200 Hectare Production Site	80
Table 5	Estimated Costs for Initial Surveying and Layout	81
Table 6	Estimated Field Maintenance and Cleaning Costs	81

EXECUTIVE SUMMARY

In recent years, the awareness of peat as a valuable source of alternate energy has grown in Newfoundland. The natural result has been the start of several small-scale peat-harvesting enterprises designed to take advantage of the abundance of peat in Newfoundland.

Production techniques used successfully in Europe however, may have to be modified for use in Newfoundland. Newfoundland receives more rainfall and fog than either Ireland or Finland (two of Europe's peat-producing countries), hence the peat fields are wetter and may require either more drainage and preparation time or the use of different preparation techniques.

Northland Associates Ltd. undertook a study on the variables that affect the preparation and drainage of peat deposits and the drying of peat sods in Newfoundland. Research was done on (1) the effectiveness of various drainage systems (5, 10, 20 meter ditch spacings), (2) the effect of various climatic and other factors on the drying of peat sods and the draining of the peat fields, (3) the effect of drainage on the drying cycle of peat sods, (4) the cost-effectiveness of various drainage systems, (5) the peat sod drying pattern of two extrusion methods.

Two sites, different in terms of climate and bog type, were chosen. The site at St. Shotts is adjacent to an already established peat mining operation that was experiencing difficulties with wet fields. The site at Markland is more typical of the peat deposits found in most of Newfoundland. It also has a less severe climate than that of St. Shotts, offering an opportunity to compare the effects of climatic factors on the drainage of peat bogs.

Weather data at each site was collected. In both cases, precipitation was judged to be a major climatic factor influencing peatland hydrology. Fog was also considered a major factor at St. Shotts but much less so in Markland because it occurred less frequently. Sun, windspeed, and air temperature were considered indirect factors in the drying of peat sods. However, because of lack of data, more specific conclusions could not be reached.

The rate of drying of peat sods was monitored only at St. Shotts (the site of the existing peat-harvesting operation). The various methods (Irish super-cutter, field press) used by the operation allowed Northland Associates to compare sod-drying rates under two conditions: the drying rate of sods extruded onto a wet surface (Irish super-cutter) vs. that of sods extruded onto a dry surface (field press). These rates were then considered in association with climatic factors.

Peat sods extruded onto a dry surface experienced a faster rate of moisture loss than those extruded onto a wet surface. Precipitation reduces the rate of moisture loss for sods on both surfaces but appeared to affect sods on a dry surface more. Sunshine, windspeed and air temperature helped increase the drying rates of peat sods but lack of local climate data made quantification impossible.

It appears from the data collected that St. Shotts is at the climatic extremity of the area that permits harvesting and drying of peat for use as fuel.

Attention was next given to the effectiveness of various drainage systems on lowering the water table and mois-

ture content of the surface layer of peat and, in particular, the cost-effectiveness of these systems. In order to produce peat as a fuel on a commercial scale, it is necessary to drain the field. A lower water table would lower the moisture content of the top layer of peat enabling it to better bear the weight of heavy equipment. Ditches dug to achieve this also become conduits for rainfall.

By comparing data from the two sites it is evident that drainage on the 5 m spaced field was better than either the 10 or 20 m fields. Data revealed that the 20 m ditch spacing in particular was very slow in draining the field.

After one year's drainage at Markland and two years at St. Shotts it appears that the water table in the 5 m and 10 m fields has reached equilibrium. Drainage appears to be adequate to take care of rainfall and runoff from snowmelt. Further lowering of the water table may occur over long periods of time or during an extremely dry season. The 20 m field, after an initial rapid decline in its water table, shows no sign of any further decline over a longer period of time.

While 5 and 10 m ditch spacing seem to be more efficient in draining peat bogs, they also seem to be less cost-effective. An analysis of the costs involved in surveying, ditching and maintaining a more intensively ditched field shows that they are not offset by the reduced time needed to drain the field properly. Unless the expenditure during the drainage period required for 5 and 10 m spacing is less than that required for the time period needed for the 20 m ditch spacing then it is not feasible to use more intensive ditching.

It is recommended that research into the effects of various drainage methods be continued for another three years. Long-term data would greatly aid the development of peat as an alternate energy source in this province and help solve any future problems that may arise. The conclusions drawn from the past three years of research are tentative because of the short time over which the research was done compared to the timespan necessary to prepare and drain a bog.

RÉSUMÉ

Au cours des dernières années, la tourbe comme source alternative d'énergie fut l'objet d'un intérêt grandissant à Terre-Neuve. Conséquemment, plusiers petites entreprises de production de tourbe ont pris naissance afin de tirer avantage de l'abondance de tourbe à Terre-Neuve.

Toutefois, les techniques de production utilisées en Europe devront être modifées pour répondre aux conditions plus rigoureuses existant à Terre-Neuve. La province reçoit plus de pluie et de brouillard que l'Irlande ou la Finlande (deux grands producteurs de tourbe de l'Europe). Donc, les conditions du terrain sont plus humides et nécessitent plus de drainage et de temps de préparation ou encore l'usage de techniques de préparation différentes.

Northland Associates Ltd. a entrepris une étude des facteurs liés à la préparation des sites de production, leur drainage, ainsi que le séchage de boudins de tourbe à Terre-Neuve. La recherche portait sur (1)l'efficacité de différents systèmes de drainage (espacement des fossés à 5, 10 et 20 mètres), (2) l'effet de certains facteurs, climatiques et autres, sur le séchage de boudins de tourbe et le drainage des champs de tourbe, (3) l'effet du drainage sur le cycle de séchage des boudins de tourbe, (4) la rentabilité des différentes méthodes de drainage, (5) les particularités de séchage de boudins de tourbe extraits selon deux méthodes différentes.

Deux sites, différents au point de vue climat et type de tourbière, ont été choisis. Le site de St. Shotts est localisé à proximité d'un site d'extraction de tourbe déjà existant et éprouvant des difficultés à cause de champs trop humides. Le site de Markland est plus typique des dépôts tourbeaux retrouvés à Terre-Neuve. Ce site jouit également d'un climat moins sévère que celui de St. Shotts; de là, l'opportunité d'évaluer l'effet du climat sur le drainage des tourbiéres.

Des données climatiques ont été recuellis aux deux sites. Dans les deux cas, les précipitations semblent être un facteur climatique déterminant dans l'hydrologie des tourbiéres. Á St. Shotts, le brouillard s'est avéré être un facteur important contrairement à Markland où il apparait moins fréquemment. L'ensoleillement, la vitesse du vent et la température ont été considérés comme facteurs agissant indirectement dans le séchage des boudins de tourbe. Cependant, à cause d'un manque de données, il à été impossible d'énoncer des conclusions plus spécifiques.

La vitesse de perte d'humidité des boudins de tourbe fut mesurée à St. Shotts seulement (sur le site même de production). Les deux techniques utilisées permirent de comparer la vitesse de séchage des boudins dans deux conditions différentes; soit sur une surface humide comme il existe sur les champs de production (méthode "Irish super-cutter"), ou sur la surface sèche du sol minèral avoisinant (méthode "field press"). Une mise en relation fut ensuite tentée entre les conditions climatiques et la vitesse de séchage.

Les boudins répandus sur une surface séche séchèrent plus rapidement que ceux répandus sur la surface humide des champs de production. Les précipitations réduisent la vitesse de séchage des boudins dans les deux cas, mais l'effet semble plus marquant sur le terrain sec. L'ensoillement, la vitesse du vent et la température contribuent à activer le séchage des boudins de tourbe, mais

le manque de données a rendu la quantification impossible.

Les données recuellis jusqu'a présent indiquent que la région de St. Shotts se situé à limite climatique permissible pour la production de tourbe combustible.

Par la suite, l'étude porta sur l'évaluation des différentes systèmes de drainage établis, de leur efficacité a baisser la nappe phréatique et l'humidité de la tourbe en surface, et la rentabilité de ces systèmes. Dans l'optique d'une production commerciale de tourbe combustible, il est nécessaire en premier lieu de drainer le site. Ainsi, la nappe phréatique abaissée permet de réduire l'humidité du sol en surface, procurant du même coup au sol une plus grande capacité portante pour supporter la machinerie lourde. Les fossés creusés agissent aussi pour éliminer les eaux de précipitation.

En comparent les données des deux sites, il est évident que le drainage des champs de production de 5m de largeur est meilleur que dans le cas de champs de 10m ou 20m de largeur. Les données indiquent aussi que l'égouttement est beaucoup plus lent pour les champs de 20m de largeur.

Après un an de drainage à Markland et deux ans à St. Shotts, il semblerait que la nappe phréatique ait atteint un seuil d'équilibre dans les champs de production de 5m et 10m. Le drainage est suffisant pour permettre d'éliminer le surplus d'eau de précipitation et au printemps. Il est encore possible que la nappe phréatique baisse un peu durant une période de sécheresse. Dans les champs de 20m, après une baisse initiale rapide, la nappe phréatique ne semble pas vouloir descendre plus bas.

Alors, que l'espacement de 5m et 10m entre les fossés semble plus efficace pour le drainage des tourbiéres, il semble également qu'ils soient moins rentables. Dans ce type d'espacement, l'analyse des coûts impliqués dans la préparation, le drainage et l'entretien indique qu'ils ne sont pas compensés par un temps de drainage plus court. Á moins que les coûts durant la période nécessaire pour drainer les champs de 5 et 10m soient moindre que ceux encourus durant la période nécessaire pour drainer les champs de 20m, il n'est pas rentable d'avoir recours à un systèmes de drainage plus serré.

Il est recommandé de continuer la recherche sur la rechcerche sur les effets de diverses méthodes de drainage pour encore trois ans. Les données à long terme aideraient d'avantage le développement de la tourbe comme source alternative d'énergie dans la province, et aiderait a régler tout problème qui pourrait subvenir. Les conclusions tirées des trois années de recherche sont encore tentatives, car les données sont incomplètes par rapport au temps réel nécessaire à mettre en production une tourbiére.

1.0 INTRODUCTION

1.1 Background

Peatlands form a large component of the island of Newfoundland. The recently completed inventory of peatlands (Northland, 1978-83) indicates that 11% of the island's land mass exists as peatland (ca. 1,114,990 hectares). These peatlands however, have not contributed significantly to resource development within the province.

Interest in the energy potential of Newfoundland's peat resources date back to at least 1865 with the establishment of a plant which supplied fuel peat to several public institutions in St. John's (Downey, 1909). Interest in fuel peat was strongest between 1900 and 1914, around 1939 and during the period 1954 to 1960. Lamaline and St. Shotts appear to be the only communities where fuel peat has been utilized extensively for long periods. With the advent of rural electrification and the presence of readily available supplies of inexpensive petroleum products, the use of peat as a fuel had become almost nonexistent by the late 1960s (Vardy, 1987).

In recent years, however, rapidly increasing oil prices coupled with uncertainties of future oil supplies, as well as the need for more effective land resource management have led to a reassessment of our peatlands for energy and resource needs. As a result, two major fuel peat demonstration projects were undertaken; one in central Newfoundland (Bishop Falls), and one in southeastern Newfoundland (St. Shotts). The Bishop Falls project produced milled fuel peat for a pulp and paper mill while the St. Shotts project concentrated on the production of peat sod for the local industrial and domestic markets. More recently, small scale commercial sod peat production projects have started in Lamaline, Stephenville and Trepassey.

In analyzing the results of these demonstration projects, especially the St. Shotts initiative, it became very evident that additional research was required to successfully produce and harvest fuel peat. In particular, it was necessary to examine the drainage system used and its relationship to the lowering of the water table over time, and the subsequent relationship to the bearing capacity of the peat surface. The St. Shotts project has suffered, and continues to suffer from wet fields, a clear indication that the present drainage system is not adequate. The climate in this area of the province is severe; excessive rainfall (annual average of 1373 mm) and fog frequency (1,145 mean annual hours of visibility 0.8 kilometres or less). No other location in the province receives as much rainfall or fog. This, combined with the fact that Newfoundland's oceanic peats are low in hydraulic conductivity (ca. 0.01×10^{-3} cm/sec vertical, 0.08×10^{-3} cm/sec lateral) (Rayment and Campbell, 1980) indicates that extreme drainage measures are necessary.

These factors often result in a high water table in the peat deposits. This leads to a loss of stability of the peat surface and reduces the trafficability of the deposit. Conventional peat production techniques demand that the first requirement is a well drained field with a firm, even, drying surface. This is necessary to permit a highly mechanized operation for producing, turning, drying and harvesting of the peat fuel. During the 1987 and 1988 production years it has been shown that even in the severe climatic conditions of the south coast of New-

foundland sod peat will dry sufficiently for use as fuel, provided it is extruded on to a well-drained dry surface.

The overall importance of peat fuel to Newfoundland's energy future needs to be placed in perspective. Biomass offers the best option for alternative fuel in the residential and industrial/commercial sectors. By far the most important source is fuelwood. However, regions of significant population base such as the Avalon and Burin peninsulas do not have an abundance of forest biomass, but do have large deposits of fuel peat. Successful development of sod peat will offer a substantial contribution towards energy self-sufficiency for some rural communities, utilizing indigenous fuel sources.

The demonstration projects have shown that peat production is directly dependent upon atmospheric conditions as well as the surface conditions of the fields themselves. This conclusion is the result of field data collected by Northland Associates Limited during 1985. However, to be successful, the fields must be better drained and prepared so that the average harvesting period is reduced from the current 90 plus days to under 40. This condition is extremely important for the successful harvesting of fuel peat in Newfoundland.

Conventional sod peat production, as successfully practised in Europe, indicates that the bog preparation phase can require between 3 and 5 years to produce a suitable drying surface and machine-workable fields. The main variables are the hydraulic conductivity of the peat soil, climatic environment, the effectiveness of the drainage system, and surface preparation. At best, it is thought that under "normal" conditions a longer period will be required to produce the desired field conditions in southeastern Newfoundland and in Newfoundland generally.

The commercial development of peatland is in its infancy in this province, but there is every indication that it may not remain that way for long. The drainage and trafficability problems currently associated with wet peatlands must be solved without delay if this large resource is to be successfully developed.

Northland was commissioned to undertake a three year study of drainage trials and sod peat drying techniques at two locations in southeastern Newfoundland where climatic conditions are severe. This study, conducted from 1986-1988, examined the moisture content and drying time of peat sods under varying conditions, and assessed the results of a number of bog draining systems.

The results of this study are presented in accordance with the terms of reference for the contract, dated 20 June, 1986 (DSS File Number 51SZ-23216-6-6098).

1.2 Objectives

The general objectives of the study were:

- *to evaluate through a series of field trials, modified drainage systems; 5, 10, 20 meter ditch spacings;*
- *to take advantage of the already advanced state of bog preparation in St. Shotts to arrive at conclusions in the earliest possible time frame;*
- *to evaluate, subject to budget and time constraints, the application of the drainage trials on virgin peatlands;*
- *to evaluate, through a series of field trials, the effect of the drainage on the drying cycle of extruded peat sods;*
- *to perform cost evaluations of the various drainage systems outlining their cost and production effectiveness in a commercial peat harvesting operation;*
- *to demonstrate through effective applied research the limitations and feasibility of conventional and modified sod peat production systems under Newfoundland conditions; and*
- *in general, to help solve the current problems associated with sod peat harvesting in Newfoundland, permitting greater utilization of this indigenous fuel source toward the goal of energy self-sufficiency.*

1.3 Report Format

The remainder of this report is divided into five parts:

- Site Descriptions. Detailed descriptions are given for the two sites (St. Shotts and Markland) at which the various phases of the study were carried out.

- Monitoring Program - Part A. Climatic data and sod peat drying study objectives, methods, results and analysis are presented in this section.
- Monitoring Program - Part B. Peatland drainage trials. A description of the objectives, methods used, trial results and analysis are presented in this section.
- Economical considerations for peatland drainage.
- Conclusions and recommendations.

2.0 SITE DESCRIPTION

Drainage trials were carried out on two different sites. The first site, ditched in late 1986, is located on a blanket bog at St. Shotts on the southerly-most portion of the Avalon Peninsula (Figure 1). The site was chosen because it is adjacent to a sod peat mining operation that has experienced operational problems associated with wet fields resulting from poor or inadequate drainage. The site was also chosen because these blanket bogs contain some of the best quality fuel peat in Newfoundland; these reserves are overlain by relatively minor levels of undecomposed peat thus allowing for easier extraction.

The second site selected is located in the central portion of the Avalon Peninsula at Markland (Figure 1). Markland was chosen because it was quite different from the St. Shotts site; the climate is quite different, with less fog and rainfall and the site is part of a slope bog-domed bog complex which is a far more typical bog type for most of Newfoundland. The peat deposit is deeper at this site and the fuel peat is overlain by an approximately 90 cm layer of horticulture grade peat (H_1-H_4 on the von Post scale).

By conducting drainage trials on two very different sites we are able to compare drainage rates, and thereby gain some insight into which type of bog can be more easily prepared for peat fuel development.

2.1 General Description of the Blanket Bogs of Southeastern Newfoundland

The following description is provided by A.M. Davis, Associate Professor of Geography, University of Toronto and is presented as background information.

The Origins and Development of Blanket Mires

The blanket mires of the southern Avalon and Burin Peninsulas of Newfoundland are confined to what Damman (1983) calls the eastern hyperoceanic barrens ecoregion which has the island's mildest winters, lowest snowfalls and most persistent fogs. Here, the mires drape across the landscape with little regard to topography. Peat depth rarely exceeds 2 m in thickness and overlies bedrock comprised of cherts, siltstone and sandstones with a veneer of Pleistocene till. These treeless mires are dominated by bryophytes and heaths. Sphagnum fuscum forms an almost continuous mat with Dicranum spp. and Rhacomitrium lanuginosum common on drier hummocks. Ericads include Empetrum nigrum, Ledum groenlandicum, Kalmia polifolia, K. angustifolia, Vaccinium vitis-idaea, and V. oxycoccus. Scirpus cespitosus is common. The communities fall mostly into the KALMIO-SPHAGNETUM FUSCI and VACCINIO-CLADONIETUM BORYI dry bog communities recognized by Wells (1981).

Through the boreal zone, peat accumulation seldom closely postdates deglaciation. Basal peat dates in eastern Canada show clusters at around 6,500 and 3,000 B.P. (Davis, 1984; Payette, 1984). For blanket mires,

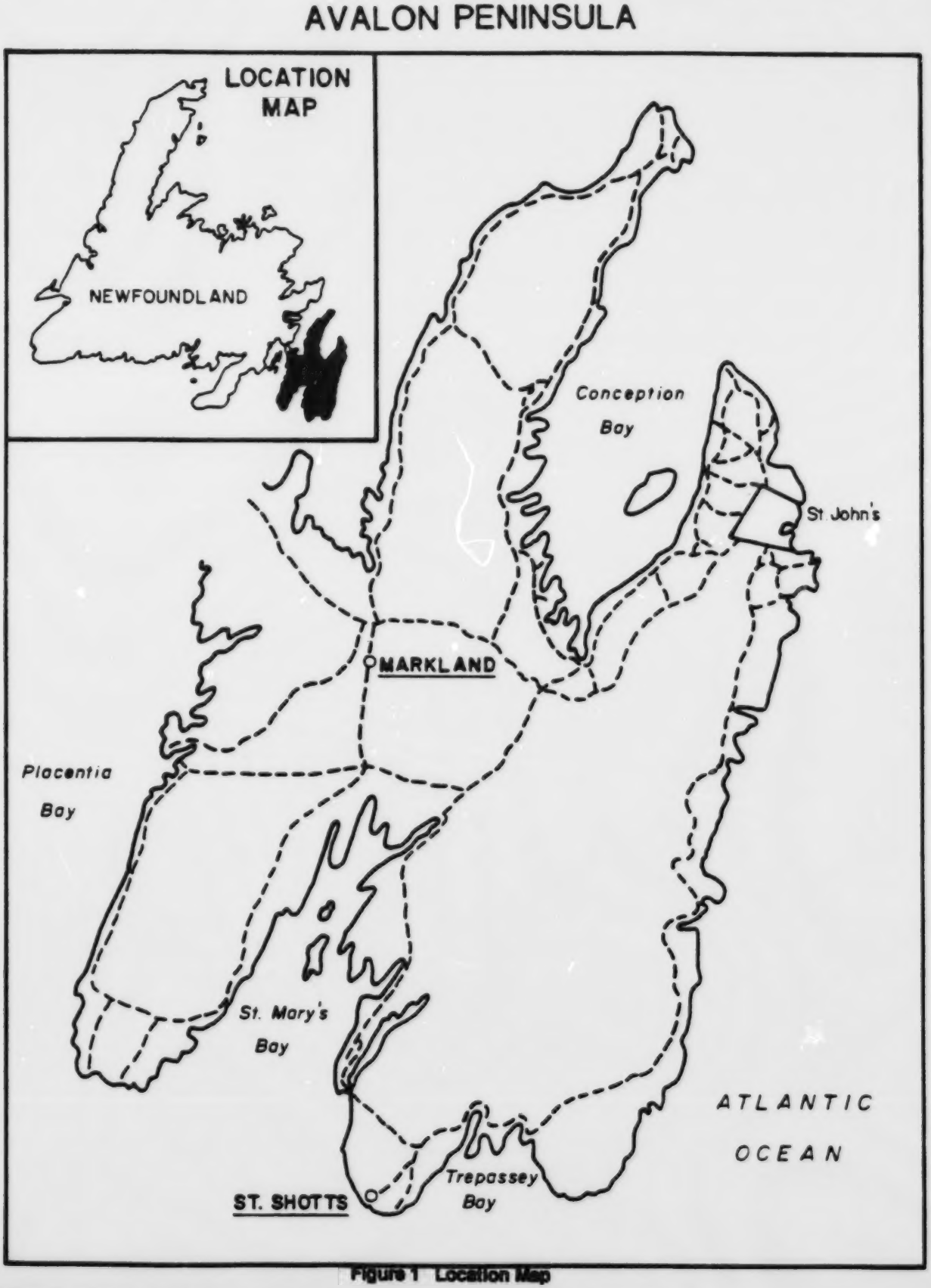


Figure 1 Location Map

the oldest dates from southeastern Newfoundland are ca. 6,000 B.P. (Davis, 1984). In the U.K. basal dates concentrate around 4,000-2,000 B.P. (Moore et al., 1984), although some blanket mires in Norway have been dated at 8,000 B.P. (Hafsten and Solem, 1976). Broad regional synchroneity of initiation implies some allogenic forcing function, presumably climate, but the common assumption that peat accumulation is triggered by climatic deterioration is untenable. Engstrom and Hansen (1985) note that paludification in Labrador appears to coincide with the onset of warmer and drier conditions. Solem (1986) recognizes a similar circumstance in Danish blanket mires.

The role of substrate remains unclear. Podzolization may be a prerequisite for paludification in some areas. In Alaska, Ugolini and Mann (1979) found a strong positive correlation between peat thickness and the degree of podzolization. Taylor and Smith (1980) recognize pedogenic and climatic peats in blanket bogs of the British Isles, with the latter succeeding the former. In the southern Avalon, there appears to be a similar distinction, but there is no evidence of podzolization. Peat appears to accumulate directly on shattered bedrock.

In the British Isles, it is generally assumed that blanket mires form in small slope concavities. Wells (1981) has suggested that Newfoundland blanket mires have a similar origin, but Hafsten and Solem (1976) and Solem (1986) found initial accumulation on convex upper slopes in Norway. Preliminary field investigation (July, 1988) at the St. Shotts site yields ambiguous information. Basal peats indicating fen conditions support the hypothesis that loci are mid-slope concavities, but the deepest accumulations occur on slope crests. The three basal 14C dates from the site are consistent with the mid-slope hypothesis. The oldest, 5710 + 60 B.P. (Beta - 28441), is from a mid-slope location. The thinner peats lower on the toe slope appear to be younger (4080 + 70 B.P., Beta - 28442). The thickest peat, towards the slope crest, is intermediate in age; 4830 + 90 B.P. (Beta - 28443).

Blanket mire formation in the southern Avalon is dissimilar to that of other ombrotropic systems since the paludification appears to have progressed across a treeless landscape. The exposures lack the woody bases typical of other peatlands. Pollen analysis from a nearby pond (Davis, unpublished) indicate treelessness throughout the Holocene.

The key to understanding the initiation and development of blanket mires is the construction of detailed microfossil and macrofossil stratigraphies. The drainage ditches associated with the Northland's project provide an unusual opportunity for this.

2.2 St. Shotts Site

The St. Shotts test site is located within a typical blanket bog. In the area surveyed, the vegetation is dominated by *Sphagnum* species, *Empetrum nigrum*, lichen (*Cladonia spp.*), with clumps of *Scirpus cespitosus*. *Rubus chamaemorus*, *Carex* and ericads species (*Ledum*, *Kalmia*, *Vaccinium*) are also common.

The peat is generally well-humified throughout the profile (H_{4-8} on the von Post scale). Sphagnum prevails in the top peat layers, but is replaced by sedge peat in the basal layers. Small amounts of shrub wood are present throughout the profile, increasing in the basal layers. Peat accumulation appears to have initiated directly on bedrock. Peat depth recorded in the test area does not exceed 2 m.

The test area is divided into 25 fields (Figure 2). The fields have a north-south orientation, and are grouped according to their width; 20 m 10 m, and 5 m. The 10 m fields are located in the western part of the test area. They are followed to the east by the 20 m and 5 m fields. Three lines of standpipes, perpendicular to the fields, were placed on nine of the fields to monitor water table fluctuations.

2.2.1 Peat Stratigraphy

The peat stratigraphy was assessed at each standpipe. The survey was conducted using a mini-McCauley sampler (5 cm core). At each sampling site, the peat stratigraphy was recorded by recovering a top to bottom core. The assessment of the peat was based on peat types and von Post humification. The peat types and humification levels were estimated directly on-site using standard field methods reported by the International Peat Society. In this case, peat type is described according to three major botanical constituents:

- moss (Sphagnum moss, brown moss) (S);
- sedge (*Carex* species, *Scirpus cespitosus* and other herb-like species) (C); and
- wood (tree wood, shrub wood) (L).

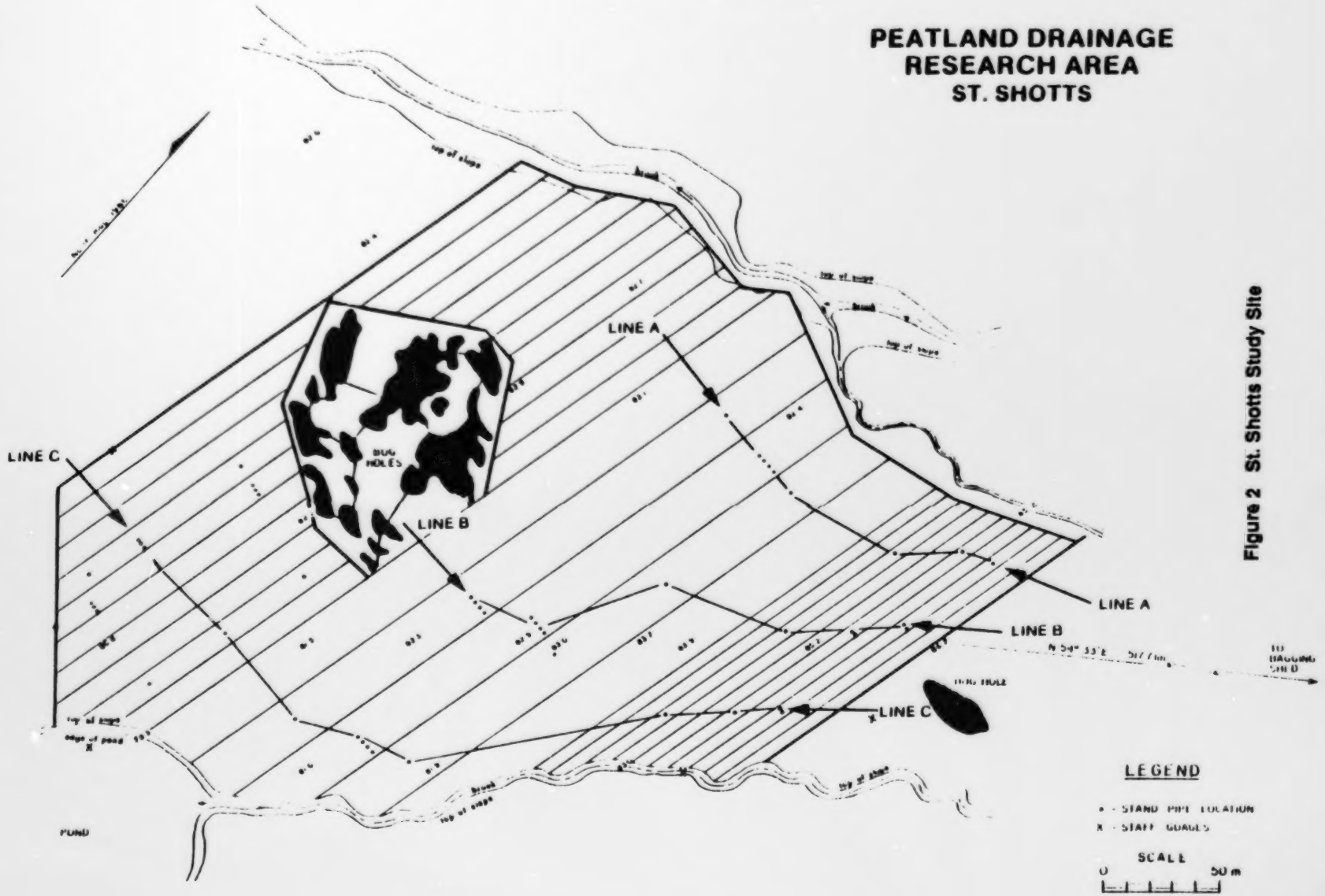


Figure 2 St. Shotts Study Site

In general, these botanical components are mixed together in various proportions in the peat mass. They rarely occur in pure state. Therefore, for mapping and classification purposes, the following combinations and codes were used in the peat profiles presented in figures 3 and 5. The same codes were also used for the Markland site.

S Moss peat (80%-100%). May contain up to 20% of sedge (C), and up to 10% of wood (L).

CS Sedge-moss peat (60%-100% moss). Contains between 30% and 40% sedge, and may contain up to 10% wood.

LS Woody-moss peat (60%-80% moss). Contains between 20% and 30% wood. May contain up to 20% sedge.

LCS Woody-sedge-moss peat (50%-60% moss). Contains between 20% and 30% wood and sedge.

C Sedge peat (80%-100%). May contain up to 20% moss (S), and up to 10% wood (L).

SC Moss-sedge peat (60%-100% sedge). Contains between 30% and 40% moss, and may contain up to 10% wood.

LC Woody-sedge peat (60%-80% sedge). Contains between 20% and 30% wood. May contain up to 20% moss.

LSC Woody-moss-sedge peat (50%-60% sedge). Contains between 20% and 30% wood and moss.

The von Post scale of humification expresses the stage of peat decomposition within a range from 1 to 10. H_1 describes the living plants, and H_{10} the totally decomposed organic matter. For clarity, the levels of decomposition in the profiles are grouped in two broad categories:

- H_1 to H_4 are grouped under the unhumified or slightly humified category, and
- H_5 to H_8 are grouped under the well-humified category.

The peat stratigraphy was classified at 37 standpipe sites. Additional sampling was performed in the northern half of fields 20-5 and 10-5, and outside the drained area.

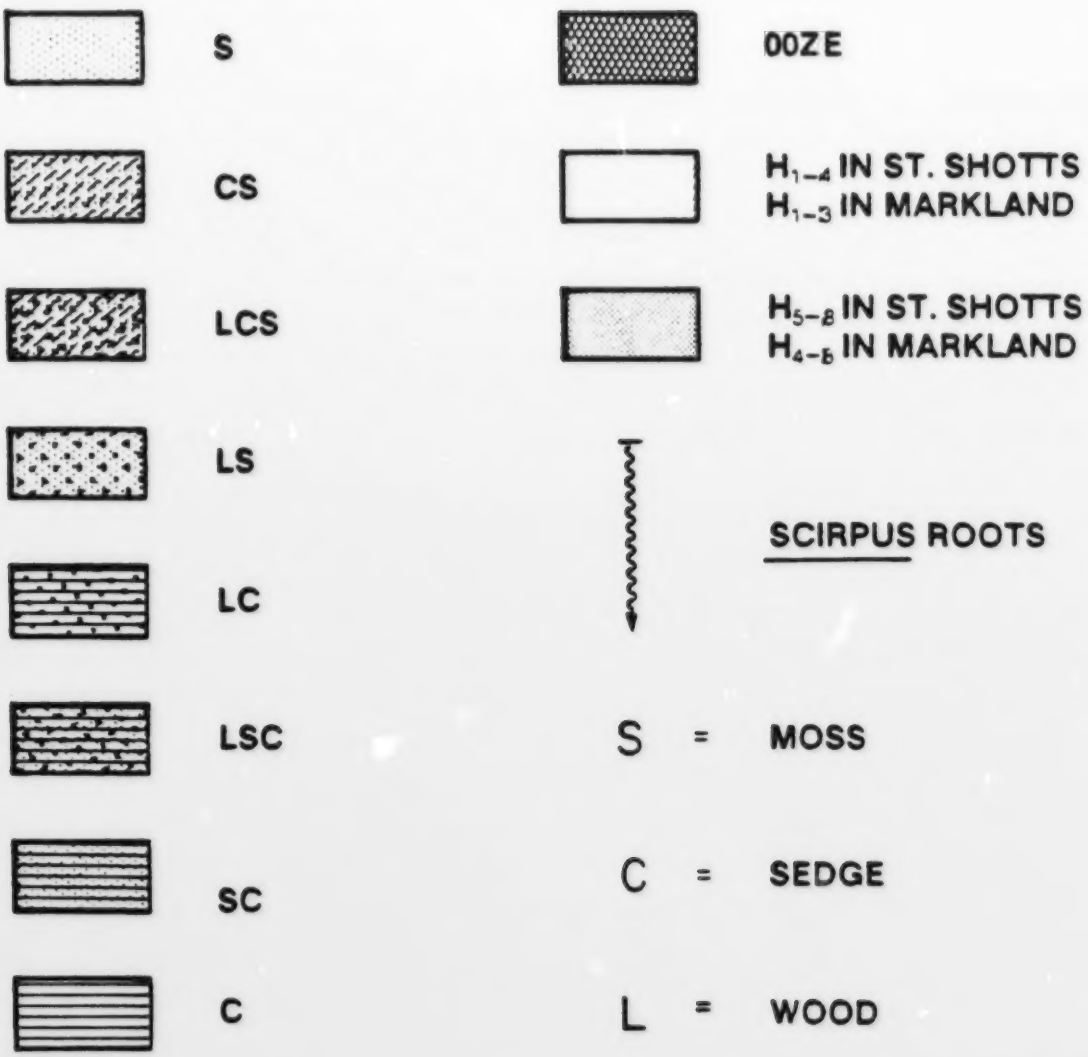
Hummock and hollow formations are not well defined in the study area. Microtopography and vegetation patterns consist of subtle changes resulting in a mosaic of different vegetation communities. The most common association is formed by sphagnum, lichen, and *Empetrum nigrum*. *Scirpus cespitosus* and *Rubus chamaemorus* occur in patches throughout the area. Sparse dwarf shrubs are also common. Similar to the surface vegetation characteristics, the underlying peat stratigraphy is relatively complex and varies vertically and laterally. Variations are often minor, or cannot be adequately characterized by the classification system used; however, broad patterns in the peat stratigraphy were identified.

Peat accumulation depths vary between 75 cm (site 5-3B) and 1.9 m (site 5-8A). In general, they range between 1 m and 1.5 m, and are largely controlled by the underlying mineral topography (Figure 3a, 3b and 3c). In almost all cases, rock was recorded for the mineral substrate, indicating that peat accumulation occurred directly on bare bedrock prior to soil-forming processes. The deepest peat was recorded along the A-line on the 5 m and 20 m fields. The relative elevation is also highest in this part of the study site. The terrain continues to slope upward east of the ditched fields and preliminary investigation shows a peat depth of more than 2 m. The presence of detritus ooze in the basal 50 cm at site 5-8A indicates that, in this immediate area, aquatic conditions prevailed in the early stages of peatland formation.

Sphagnum, sedge, and shrub species are the major botanical peat-forming components in this area. The level of decomposition varies from medium to well-humified, ranging from H_4 to H_8 on the von Post scale (Figure 3a, 3b and 3c). No relationship is evident between levels of humification and botanical composition. Higher humification classes are more common in the basal layers; however, a banded structure is visible in the 20 m fields along the B-line and C-line. In this case, the top to bottom sequence is as follows: slightly humified (H_{3-4}); well-humified (H_{5-7}); slightly humified (H_{3-4}); and finally, well-humified (H_{5-7}). This sequence is probably indicative of local cyclical processes and hydrologically controlled.

The stratigraphy is mostly composed of well-humified (H_{4-8}) Sphagnum and sedge peat. Shrub wood is also present in small proportion throughout the profile, and increases up to 20% in the basal layers. Sphagnum is the dominant component in the surface layers, but sedge is often dominant in the basal layers. In most cases the peat consists of a mixture of sedge and Sphagnum in variable proportions. Sedge is dominant, especially along the A-line on the 5 m and 20 m fields. Minor shrub wood fractions are present throughout the profile, but become more common in the basal layers where they can reach

LEGEND



Legend for figures 3(a), 3(b), 3(c).

ST. SHOTTS

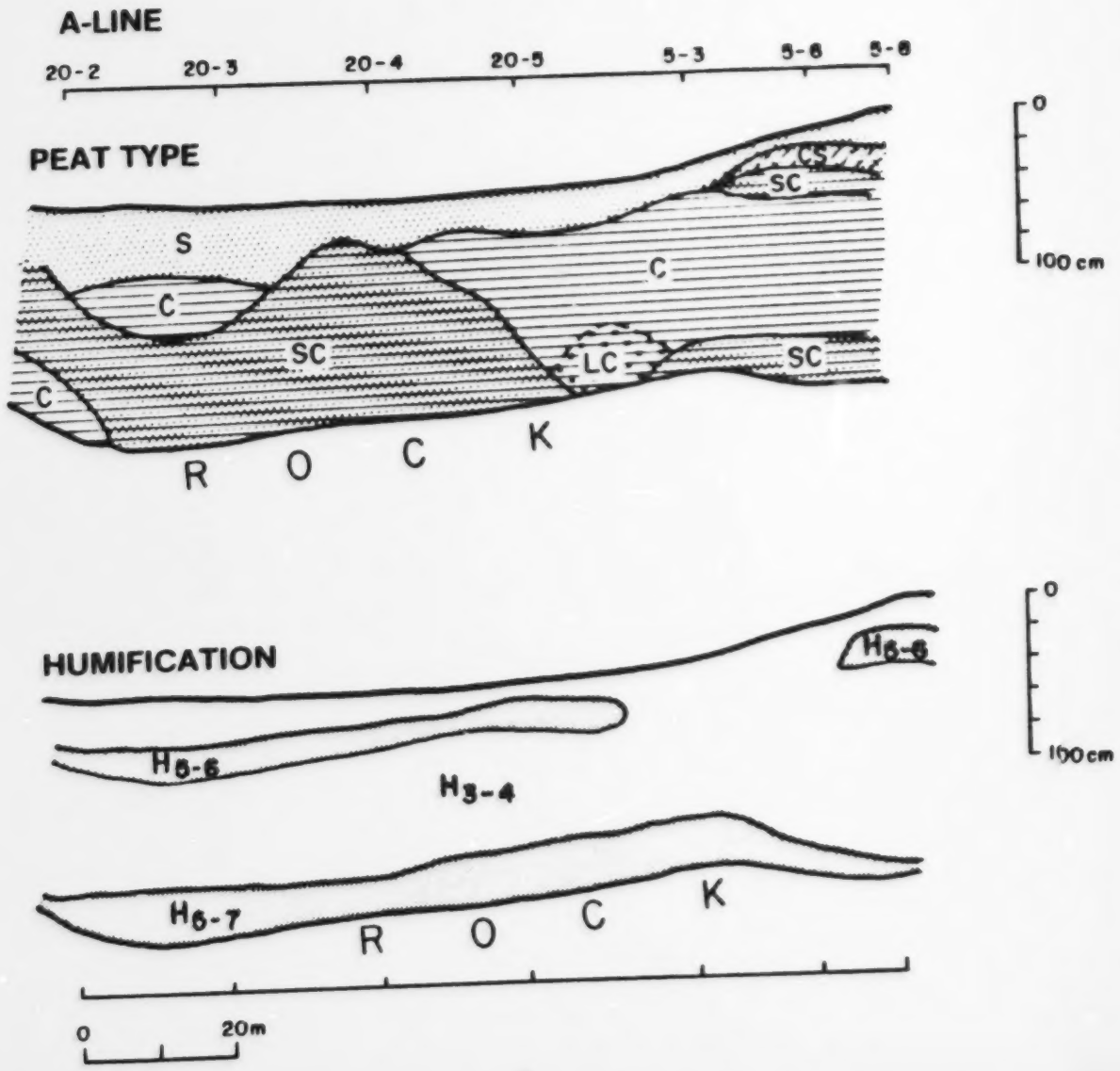


Figure 3(a) Peat Profiles, A-line, St. Shotts

ST. SHOTTS

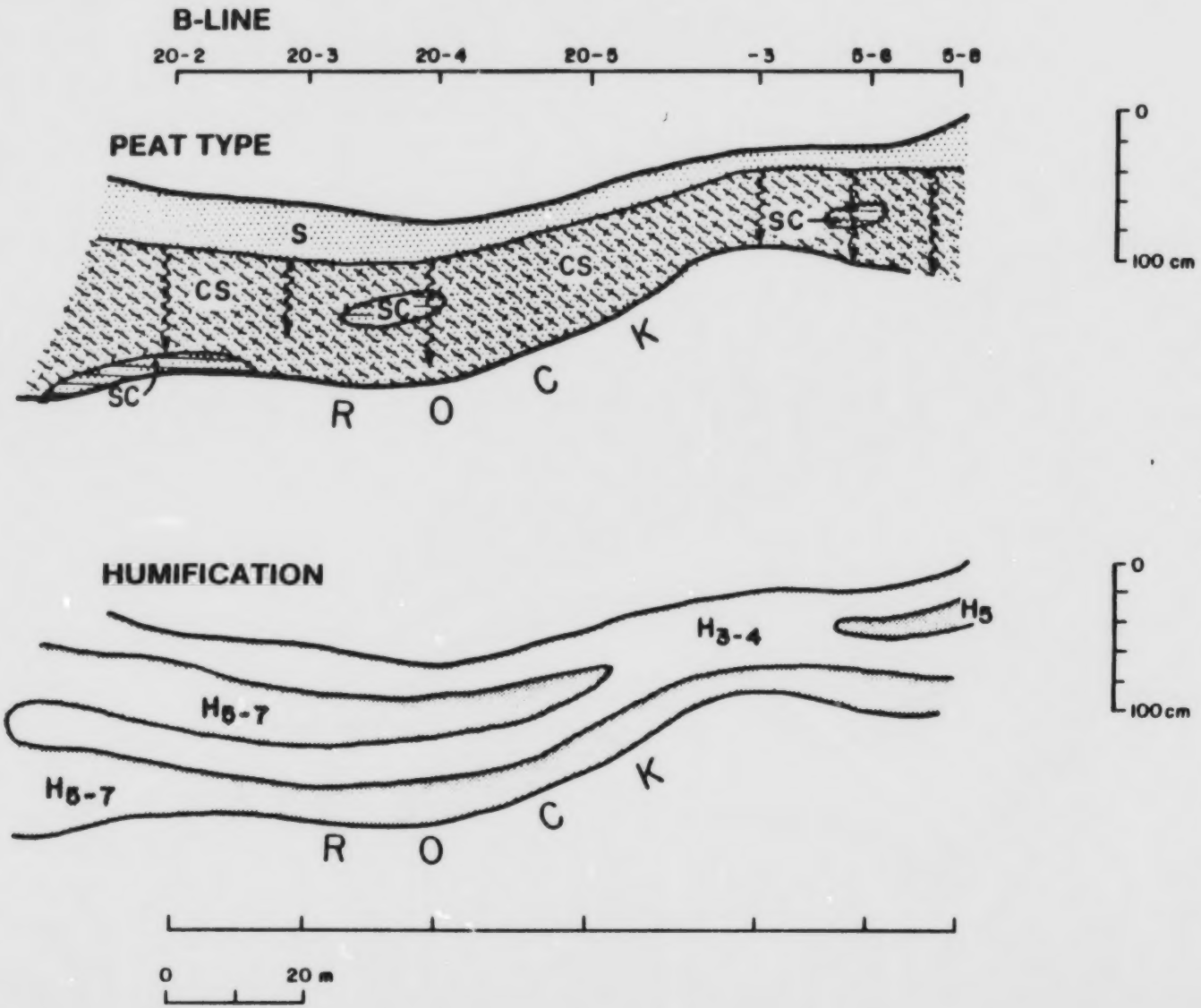


Figure 3(b) Peat Profiles, B-Line, St. Shotts

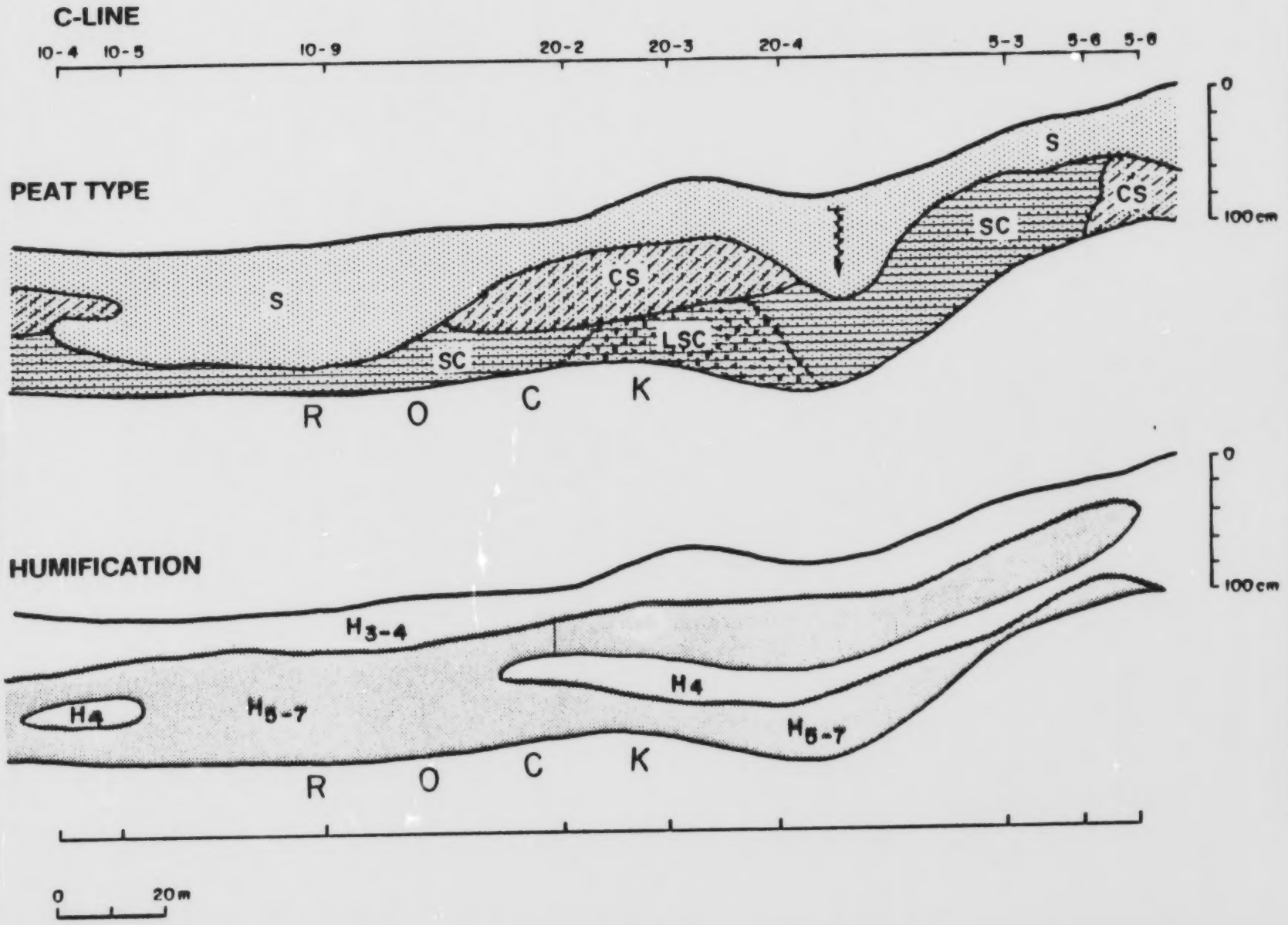


Figure 3(c) Peat Profiles, C-Line, St. Shotts

up to 20% of the peat mass especially in association with sedge peat.

Sphagnum is the dominant component throughout the peat profile, except in the basal layers where sedge often dominates. An exception is the northeast part of the drained area, along line A on the 5 m and 20 m fields, where Sphagnum dominates only in the top 20-50 cm of the peat profile, and is replaced by sedge throughout the remainder of the profile. In the 10 m fields, the top 50 cm is composed almost entirely of Sphagnum peat (90%-100%). In the remainder of the drained area, there is always a 20%-30% component of sedge mixed in the peat.

Along the B line on the 5 m and 20 m fields, approximately 30% of the peat mass consists of very long and strong fibres. These fibres originate from the *Scirpus cespitosus* intricate root system. Peat moss humification is difficult to assess in the presence of these roots since many of the associated root fibres are still alive and are mixed with a very old and partly decomposed peat matrix. This occurs for example, where the matrix is well-humified. It is not yet known if the humification resulting from this combination has the same meaning as it does with more homogenous peat. These fibres are not as dense, or are absent in the remainder of the drained area.

2.3 Markland Site

The Markland study site is located within a large slope bog/domed bog complex. The test area contains no major topographical breaks, and is technically easily exploitable. The surface microtopography is, however, more accentuated than in St. Shotts, as well-defined hummocks-hollows formations cover most of the surface. In general, the height of the hummocks is less than 30 cm above the hollow phase. The vegetation consists mainly of *Sphagnum* species with *Empetrum nigrum*, *Scirpus cespitosus* and lichen. *Rubus chamaemorus*, ericads such as *Ledum*, *Kalmia*, *Vaccinium*, and stunted spruces are also common especially associated with hummocks. *Scirpus cespitosus* and lichen are present mostly in hollows. Lichen, and *Empetrum nigrum* are, however, not as common as in St. Shotts.

Peat depth is greater than on blanket bogs, and varies usually between 1.5 m and 2.5 m. Depths of 3 m were also recorded in the western end of the test area. The peat stratigraphy contains a relatively thick layer (up to 1.5 m) of unhumified (H_{1-3} on the von Post scale) peat overlaying more humified (H_{4-8} on the von Post scale) peat. Sphagnum is the major peat forming material and occurs in almost pure state throughout the top layers. Sedge and shrub wood are more common in the basal layers. The stratigraphy in the top layers shows a well-defined banded structure resulting from cyclical regeneration mechanism during the peat accumulation process. The concept of cyclical regeneration in ombrotrophic peatlands is well documented, and examples of interpretations can be found in Barber (1981), Tolonen *et al.* (1985), Davis (1984), and in Davis and Wickham (1987).

The five hectare test site contains 21 ditched fields. These fields have an east-west orientation with a westward drainage (Figure 4). The distribution of the 5 m, 10 m, and 20 m fields differs from that on the St. Shotts site. Here, the various field sizes are distributed evenly throughout the test area rather than being grouped as is the case in St. Shotts. Three lines of standpipes were installed on 14 fields and arranged perpendicular to the field direction to allow the monitoring of water table fluctuations.

2.3.1 Peat Stratigraphy

Peat stratigraphy was assessed at each standpipe using the same field methods and classification system as in St. Shotts. The classification system and codes used for peat type are presented in Section 2.2.1. However, in the profiles (figures 5a, 5b and 5c), the von Post degrees of humification, are grouped differently:

- H_1 to H_3 are grouped under the unhumified or slightly humified category, and
- H_4 to H_8 are grouped under the well-humified category.

The peat stratigraphy was classified at 40 standpipe sites and in the eastern half of field 20-14.

In the test area, surface microtopography and vegetation patterns show two distinct formations. The eastern half consists of a hummocky surface with *Sphagnum* and shrubs as the dominant species. *Scirpus cespitosus* and lichen are also common, especially in the hollows. Unlike the hummocky surface described above, the western half, and especially the southwest corner of the test area (between 14B-18B and 11C-18C) presents a relatively flat, lawn-type surface where *Scirpus cespitosus* grows uniformly. In this part of the peatland, hummock-hollow formations are not well developed. This hummocky-

lawn change visible at the surface can be traced down to a certain point to the peat stratigraphy where correspondent variations can be found. The peat stratigraphy is relatively complex, especially in the hummocky surface area where the peat profile contains numerous layers formed during the hummock-hollow successions. Variations are often minor, or cannot be adequately characterized by the classification system used; however, broad patterns in the peat stratigraphy were identified.

Peat accumulation varies between 1.5 m and 3 m throughout most of the surveyed area (Figure 4). A small outcrop is present at the highest end (east end) of fields 6 and 7, but dips relatively fast under the peat. The deepest peat (2.5 m - 3 m) occurs in the western end (along the C-line), and in the southeastern end (adjacent to the A-line). The remaining area measures between 1.5 m and 2.5 m of peat. Locally, the terrain slopes in a southwest direction. Peat depth is relatively variable and surface topography closely follows the underlying mineral soil topography. Contrary to the St. Shotts site, peat depths tend to increase in topographical lows (or concavities).

The botanical composition of the peat is mainly Sphagnum, sedge, and wood. Although Sphagnum, which is the most common botanical component, is present throughout in variable proportions, it becomes prevalent in the surface layers, where edaphic conditions become decreasingly conducive for other species. Sedge and wood are more common in the lower peat layers, but are also present to a lesser degree higher in the peat strata. Sedge-dominated peat is usually mixed with 30%-40% Sphagnum, and unlike St. Shotts, rarely occurs in a pure state. The wood component originates primarily from shrub species, and rarely exceeds 20% of the peat volume when present.

Figures 5a, 5b and 5c show the peat type and humification profiles along the three standpipe lines across the fields. In the northern (Fields 1 to 11) and eastern (A-line) parts of the study area where hummocky surfaces dominate, almost pure Sphagnum layers (80%-100%) with typically cyclical patterns are present in the top 1.5 m of peat. However on fields 9 and 10 along the A-line, the cyclical patterns become unclear, with the average humification and the proportion of sedge being higher. The presence of a dense *Scirpus* root system is also noticeable at these two sites. The humification levels alternate between H_3 (light layer) and H_6 (dark layer). The more humified layers are usually less than 10 cm, and are frequently 1 cm or less. No detailed examinations were performed on the dark layers, but the sedge content tends to be higher and, in some cases, detritus ooze was identified. The presence of detritus ooze indicates that standing water was present during some of the hollow-pool phases. Laterally, no continuity was noticed in the cyclical pattern between sites.

In the southwest portion of the test area (fields 14 to 18 along the B and C lines), the banded structure in the peat stratigraphy is absent or not clearly defined. The sedge content in the top peat layers is higher (20%-30%) than in the other areas, and is due mainly to the presence of *Scirpus cespitosus* root fibres. As well, the humification level is higher in the top layers (H_4 rather than H_3). In this part of the deposit, the moisture content of the peat is higher, especially in the basal layers.

The more humified basal layers (H_{6-7}), show no definite spatial patterns, in terms of peat type, that could be related to surface characteristics. Wood and sedge percentages are higher than near the surface. The wood and shrub wood fraction rarely exceeds 20% of the peat volume when present.

For some of the sites surveyed a thin layer (20 cm or less) of detritus ooze (*gyttja*) or muddy peat (mineral-organic mixture) was recorded at the base of the peat layer. Gyttja is an organic-rich deposit occurring in shallow water. It has a high mineral content, and is not classified as peat. This also exists as patches below the peat and indicates that small pools (catchments) were present during the early stage of development of this portion of the peatland deposit. The presence of wood and shrub wood in the basal layer of many of the sites surveyed suggests that bog formation also proceeded through paludification of a tundra-like, or open forest terrain. Most of the woody peat surveyed originated as shrub wood. Only limited amounts of tree wood were found.

In the area surveyed, peat has formed over a predominantly clayey till. Clay, silt, gravel and rock were also recorded.

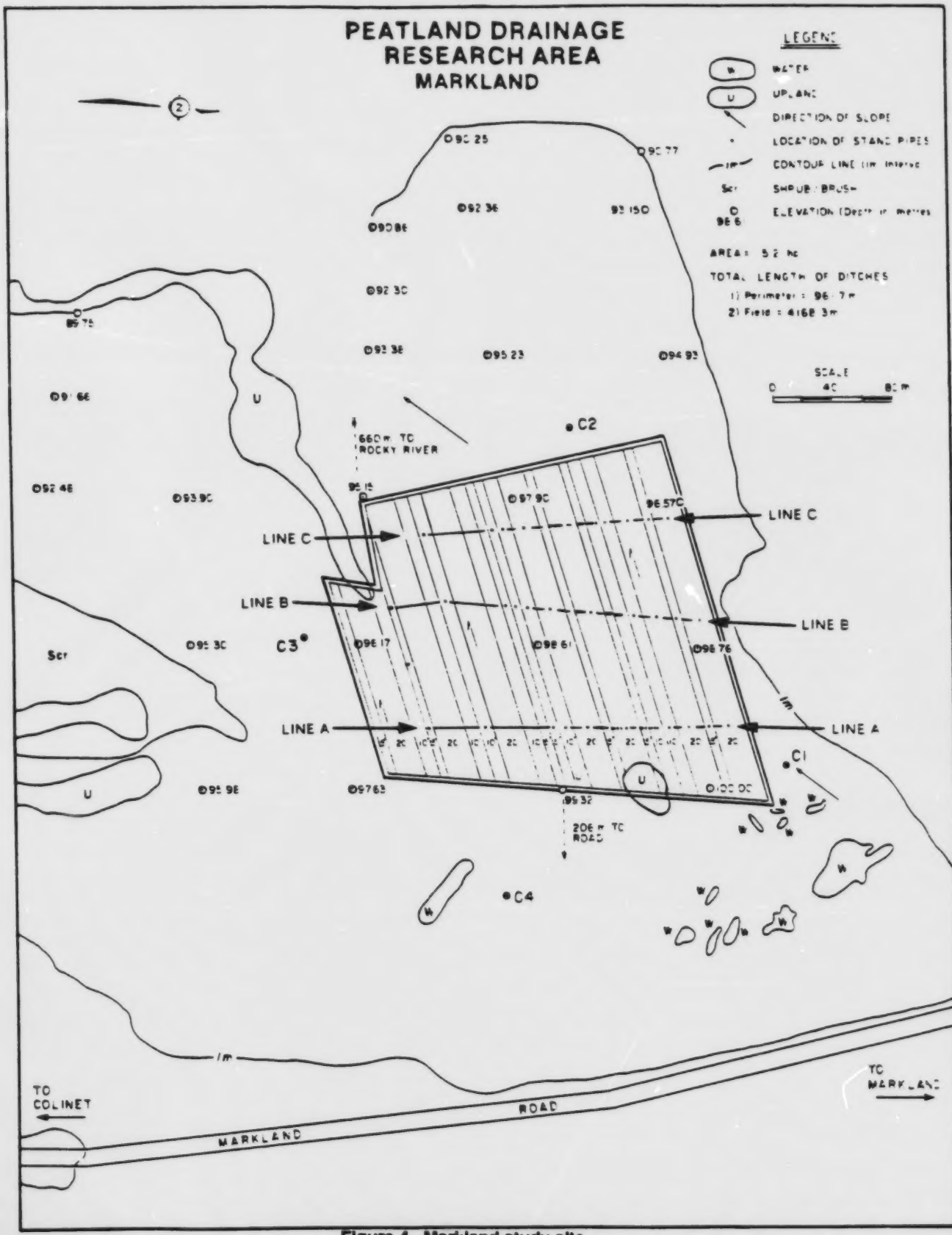


Figure 4 Markland study site

MARKLAND

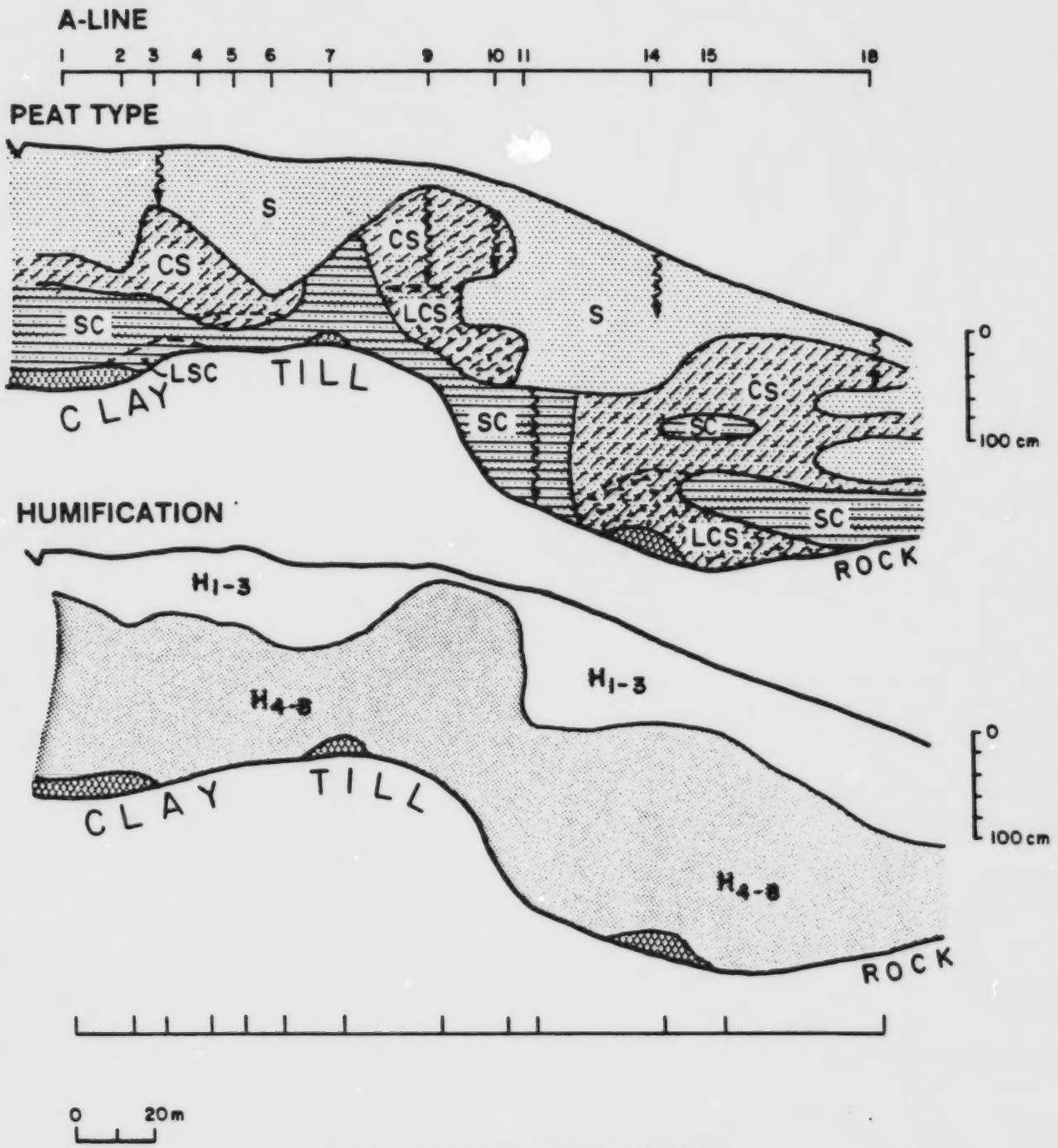


Figure 5(a) Peat Profiles, A-Line, Markland

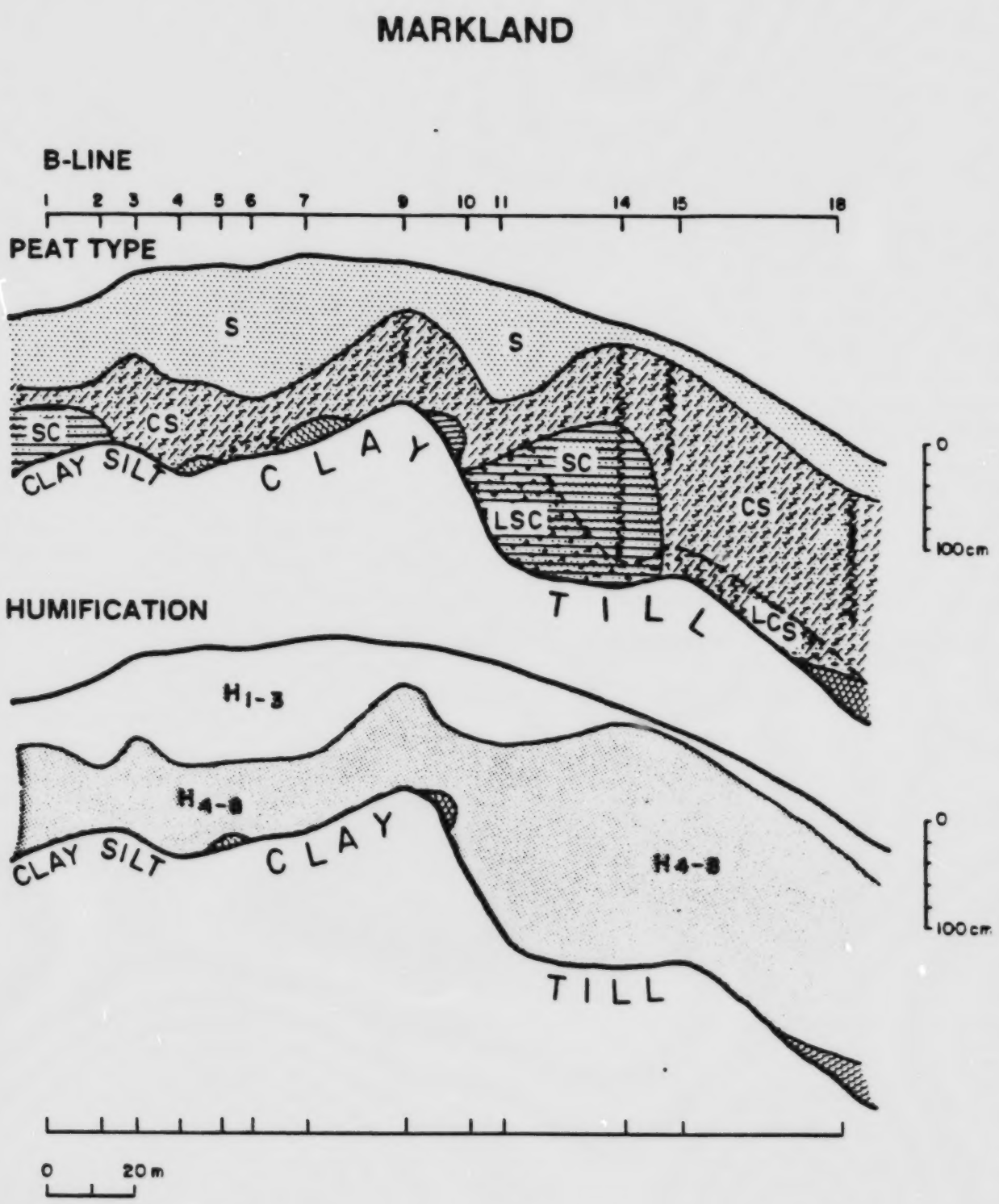


Figure 5(b) Peat Profiles, B-Line, Markland

MARKLAND

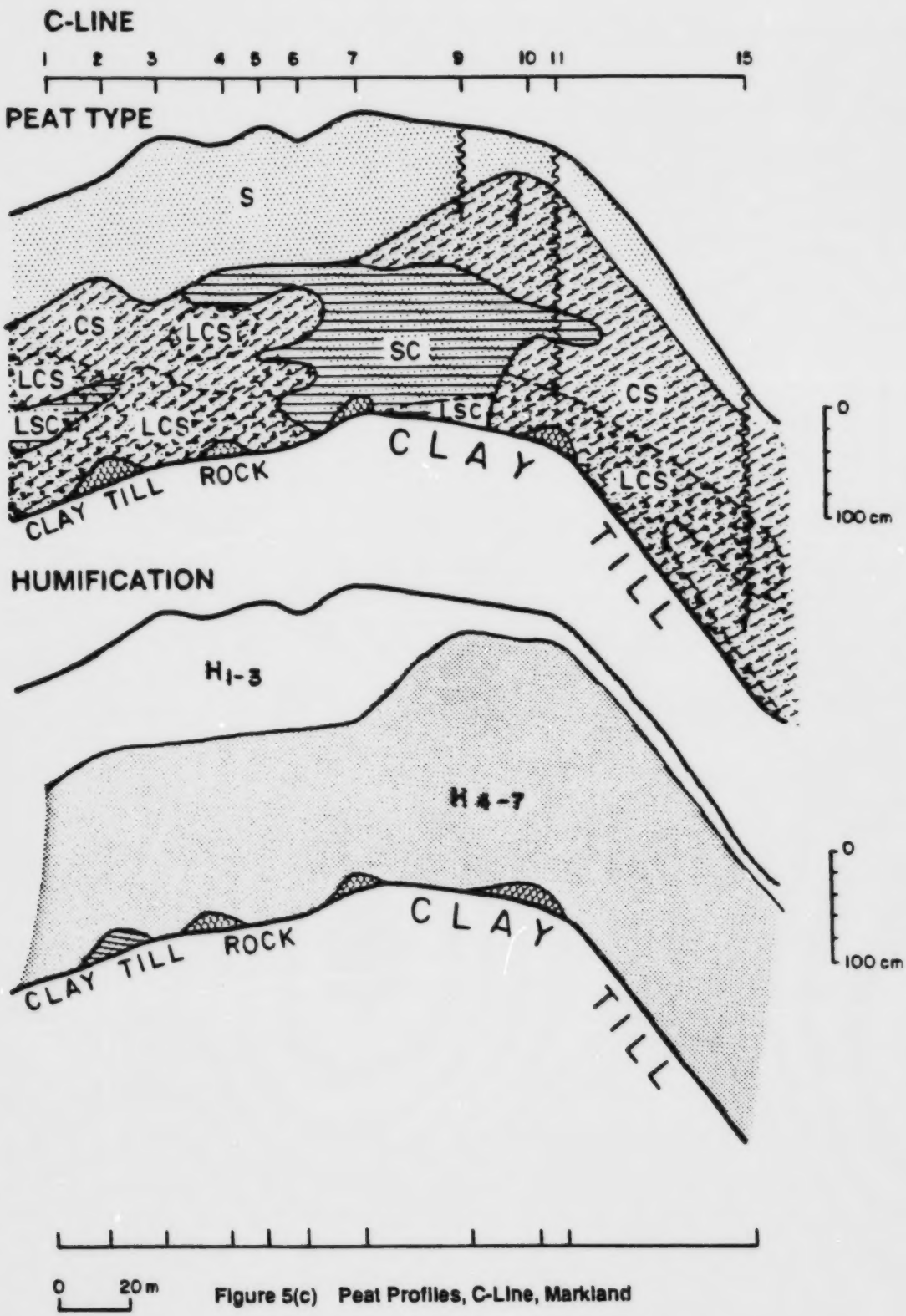


Figure 5(c) Peat Profiles, C-Line, Markland

3.0 MONITORING PROGRAM - PART A

Little is known about the drainage rates and the bearing capacity of Newfoundland's peatlands with respect to peat harvesting operations. To provide the database necessary to achieve the overall objectives of this study, an intensive monitoring program was designed to generate answers to a number of basic questions: How much faster will a 5 meter peat field drain as opposed to a 10 meter or 20 meter field? Can a wider peat field (such as 20 meter ditch spacings) achieve the same lowering of the water table as a narrow field (5 or 10 meter) if left to drain longer? How long is required after the initial drainage before the peat fields are dry enough to begin the field preparation for a peat harvesting operation? Is the common Irish practice of allowing a 5-year drainage period before operations begin sufficient in the harsh environment of the southern Avalon, or is a longer time period required to compensate for the increased rainfall? These are some of the questions that the data provided by our monitoring program would help in answering.

The monitoring program was designed to provide base data for the following four major parameters and is presented in two parts - Part A and Part B as follows:

Part A

1. climatic conditions,
2. drying times of extruded peat sods,

Part B

3. moisture contents of the surface peat layer, and
4. water table levels.

3.1 Climatic Data

Climate is a major factor influencing peatland drainage results. Climatic variables such as precipitation and fog for example, contribute to the input of water in the system; evaporation and evapotranspiration contribute to water output. The effect on peatland hydrology of other climatic variables such as temperature, wind, sunshine etc. is not direct and will depend on how these variables and others interact over time.

The standard AES weather station, operating at St. Shotts since 1978, has been used as the source of weather data for this study. In addition, a weather sub-station operated by Avalon Peat Harvesting is located 0.5 km from our drainage site. This sub-station provided much of the data from June to October 1986-1988 for this study.

Unfortunately there is no weather station located at the Markland study site. The nearest station is approximately 12 km to the south at Colinet. Preliminary analysis indicates that Colinet and Markland are climatologically different and extrapolation of weather data from the Colinet station to the Markland site has no statistical validity. To partially overcome this deficiency a rain gauge was installed near the Markland site during the summer of 1988.

In this section, the available weather data will be examined.

3.1.1 Precipitation

The precipitation data for St. Shotts are presented in Figure 6. This figure provides a comparison of the summer monthly rainfall values from 1986-1988. These are also compared to the long-term averages for the area. At St. Shotts, the average monthly precipitation from June to August is in the range of 100 mm to 110 mm. However, during September the average precipitation level increases to 133 mm. This is extremely important when we consider that late August-mid September is the normal harvest time for the sod peat operation. The increased rainfall in September makes the field wetter and thus harvesting is more difficult. It can be seen from the data that an extremely dry summer was experienced in 1987, the first full year of drainage at the St. Shotts site. In fact, from June to September the site received 50% less rainfall than in an average year (227 mm compared to 458 mm). The months of June and July were the driest with 46 mm and 40 mm respectively compared with averages of 104 mm and 112 mm. This dry period had a very drastic effect on the water table levels in the peat fields and the moisture content of the peat sods, as well as the *in situ* surface peat layers. This effect will be examined and discussed under the appropriate section later in this report.

It can also be seen from the data that during the summers of 1986 and 1988 the month of June, and to a lesser degree, July were wetter than normal. In 1986 only the month of September was markedly drier than average. Similarly in 1988, only the month of July was drier than normal. These factors are important in the context of their effect on the water table levels and peat moisture content, as will be seen when we discuss these parameters.

It will be helpful to understand just how adverse the climatic environment is in the southern Avalon within the context of peatland drainage. For this reason we present Figure 7, which provides a comparison of the average May to September precipitation at Finland, Ireland and St. Shotts. Finland and Ireland were chosen because both countries are among the leaders in the drainage of peatlands for development. It can be seen from the figure that the frequency and quantity of precipitation at St. Shotts is far greater than that of either Finland or Ireland. The peat production areas of Finland and Ireland receive only half and two thirds respectively of the rain that falls in St. Shotts. It is clearly evident that the amount of rainfall at St. Shotts is a major limiting factor in the draining of the blanket bog and the subsequent drying of peat.

For the Markland test site, the analysis of the rainfall data from the incomplete data sets indicates that the overall summer precipitation during 1988, the first year of drainage for this site was not significantly different from St. Shotts.

3.1.2 Fog

The amount of fog is an important factor in contributing to a positive water balance in peatland environments. Fog can add a considerable amount of water to an area thus inhibiting drainage and the drying of peat. Fog occurs frequently at St. Shotts. Hare (1952) presents data on the frequency of fog over the marine inshore and coastal waters. During the summer period (June, July, August), the southern Avalon ranks as the foggiest or second foggiest coastal area on the island, with this phenomenon occurring on 41% of the observations in July. The situation improves considerably in September, with the southern Avalon ranking fourth. These data by Hare (1952) are for the periods 1883 and 1921-38, and represent the longest fog-frequency data available.

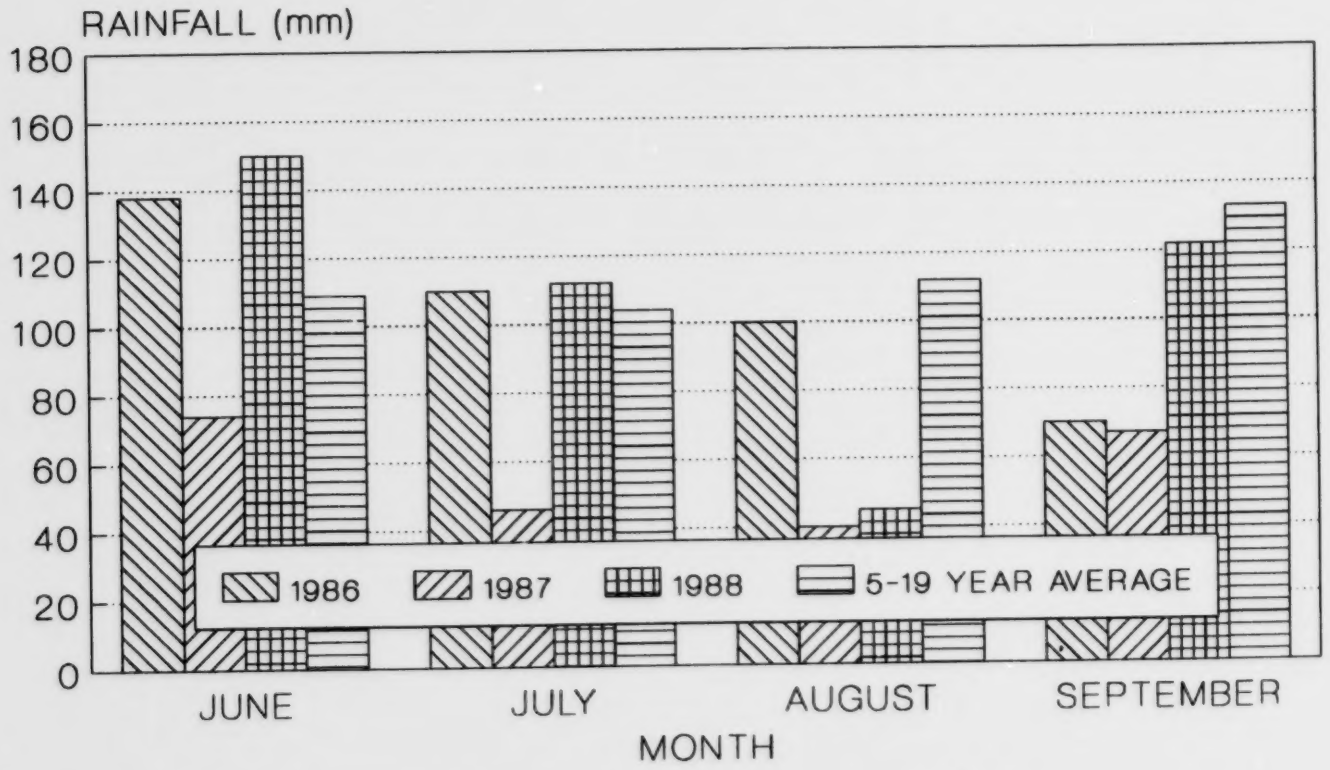
No data on fog are readily available for the Markland area, but because of its inland location and observations made during the course of the field program in 1987 and 1988 it is concluded that fog is not a limiting factor in the drainage of the local peatlands.

3.1.3 Sunshine, Wind Speed and Air Temperature

These climatic factors play a role in a peatland harvesting operation and therefore must be considered when selecting a site for such development. While these factors are important in peatland drainage they exert an even greater influence in the production of both milled and fuel peat due to their collective influence in the drying of peat.

(a)Sunshine

The distribution of sunshine hours varies throughout the period from June to September at St. Shotts (Table 1). The 6-year average total sunshine hours for St. Shotts (700 hours) is 60% less than the average number of May-September hours of sunshine (1,113 hours) for the Finnish peat harvesting areas. None of the Maritime Provinces or Ontario potential peatland developments with which we are familiar experience such a reduced sunshine budget.



NB. The 1987 rainfall for the drying period (June-Sept) was 50% less than the average rainfall for that period.

Figure 6 Comparison of Yearly Rainfall - St. Shotts

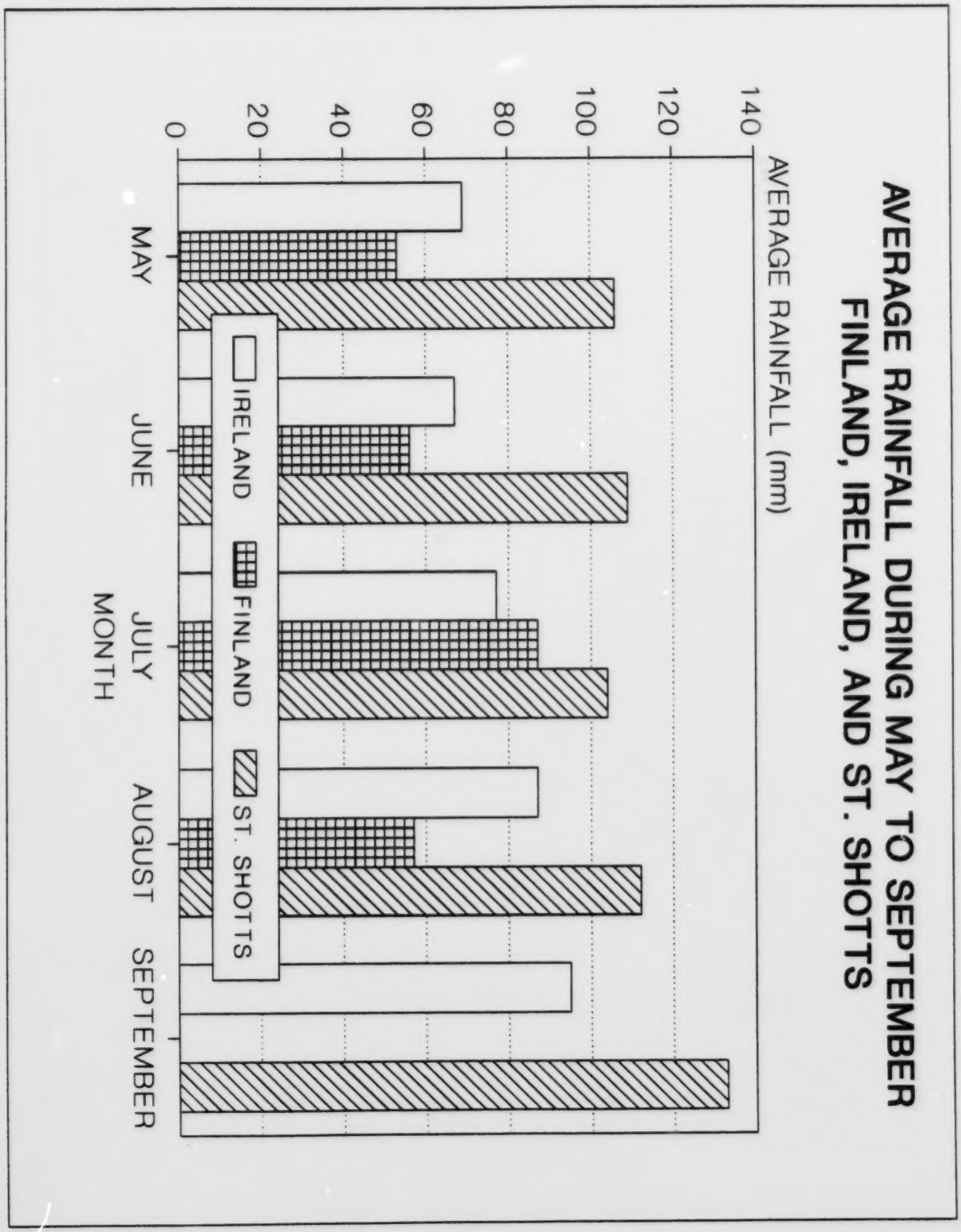


Figure 7 Average Rainfall - May to September

TABLE 1: Hours of Sunshine, June - September Period, St. Shotts 1978-1983

	June	July	Aug.	Sept.	Totals
1983	119	122	138	95	572
1982	164	135	178	122	734
1981	145	151	164	130	740
1980	148	88	155	160	681
1979	170	149	116	153	679
1978	131	171	180	132	793
	877	816	931	792	4,199

(b)Windspeed

Frequent moderately steady winds are very effective in drying drained peat fields and extruded sods. The average monthly wind speeds for the St. Shotts site during the summers of 1987 and 1988 are shown below.

		June	July	Aug.	Sept.
Wind Velocity	1987	6.5	4.6	4.2	7.6
Monthly Average km/hr	1988	7.2	5.3	5.7	6.7

(c)Air Temperature

Air temperature plays an important role in the drying of peat through evaporation and evapotranspiration. While no data are available for the average daily temperature at St. Shotts, there are data available for the average daily maximum and minimum temperature for the months of June to September. These are presented below.

		June	July	Aug.	Sept.	Average for the Season
Long Term Average	max.	11.1	15.2	16.9	14.8	14.5
	min.	4.8	9.4	11.4	8.7	8.6
1986	max.	13.0	14.1	16.4	14.0	14.4
	min.	7.6	9.0	11.2	6.9	8.7
1987	max.	12.1	17.8	18.0	14.6	15.6
	min.	5.4	10.2	10.9	8.7	8.8

1988	max.12.7	15.8	18.0	15.8	15.6
	min. 6.4	10.5	11.1	8.6	9.2

It can be seen from the above data that in terms of the maximum and minimum air temperature both 1987 and 1988 were above normal years.

3.1.4 Summary

St. Shotts and Markland exhibit much higher precipitation levels over the summer months than peat production areas of Ireland or Finland. This serves to lengthen the period necessary for local peatland drainage and for sod drying. The persistence of fog also contributes to hamper the drainage and drying of peat; this is significant at coastal St. Shotts but not at Markland. A positive relationship exists between sunshine, wind speed and air temperature and peat sods drying rates. A lack of suitable data precludes related quantification on a local level. This remains an area of possible future research.

3.2 Sod Peat Drying Monitoring Activities

This program was conducted only on the peat fields controlled by Avalon Peat Harvesting at St. Shotts (Figure 8), and was restricted to monitoring of the moisture contents of peat sods extruded during the normal operations at the site.

This section of the report will discuss the results of the monitoring activities.

3.2.1 Objectives

The general objective was to determine and compare the drying rate of peat sods extruded on a variety of field conditions. This original objective was modified during the second year of the project (1987). It was originally intended to cut peat on all of the company's operational fields and thus monitor the moisture contents of the sods throughout the complete drying cycle (i.e. from extrusion in early June to harvesting in September). However, because of poor drainage conditions resulting in wet fields, Avalon Peat Harvesting in 1987 purchased a field press extruder. This enabled the extraction of bulk peat from the field for transport to a nearby upland location where it was then extruded on a dry ground surface. In 1987 and again in 1988 the majority of the peat sods were produced in this manner.

The company continued to cut peat on its fields with the Irish cutter to sell to customers under a super saver program. Under this arrangement the customer would lease a plot of peatland on which Avalon Peat Harvesting would subsequently cut the sods. The customers then would be responsible for harvesting. The two cutting methods employed by Avalon Peat Harvesting allowed the comparison of sod drying rates under very different drying conditions, i.e. dry surface vs wet surface.

3.2.2 Description of Cutting Methods

The Irish Super Cutter Method - with this method the sod fuel peat is extruded directly onto the field surface by the super cutter. This is accomplished through use of a large chain-saw-like blade cutting vertically into the field. As the tractor moves along the field, peat is cut by the blade and moved to the surface along a rotating chain where it is passed through a compression auger. It is then compressed and finally extruded onto the peatland surface. The peat sods remain on the surface of the peat field to dry under natural conditions. At time of extrusion the moisture content of the sods is usually between 85-90%. Harvesting is carried out when the moisture content falls to 45% or below. With this method, the drying time is directly dependent upon the amount of post-extrusion rainfall and the condition of the peatland surface layer on which the sods are drying. If the fields are wet as a result of heavy rain and poor drainage conditions the drying time required to lower the moisture contents from 85% to 45% is much longer.

The Field Press Method - with this method the raw peat is excavated by means of a backhoe from the site, loaded into a hopper-type trailer attachment and transported to a nearby dry mineral surface where it is then extruded. The drying time required for the sods to reach 45% moisture content is dependent on rainfall and other drying conditions. It is not affected however by a wet ground surface as in the case when sods remain on the peat fields as with the super cutter method.

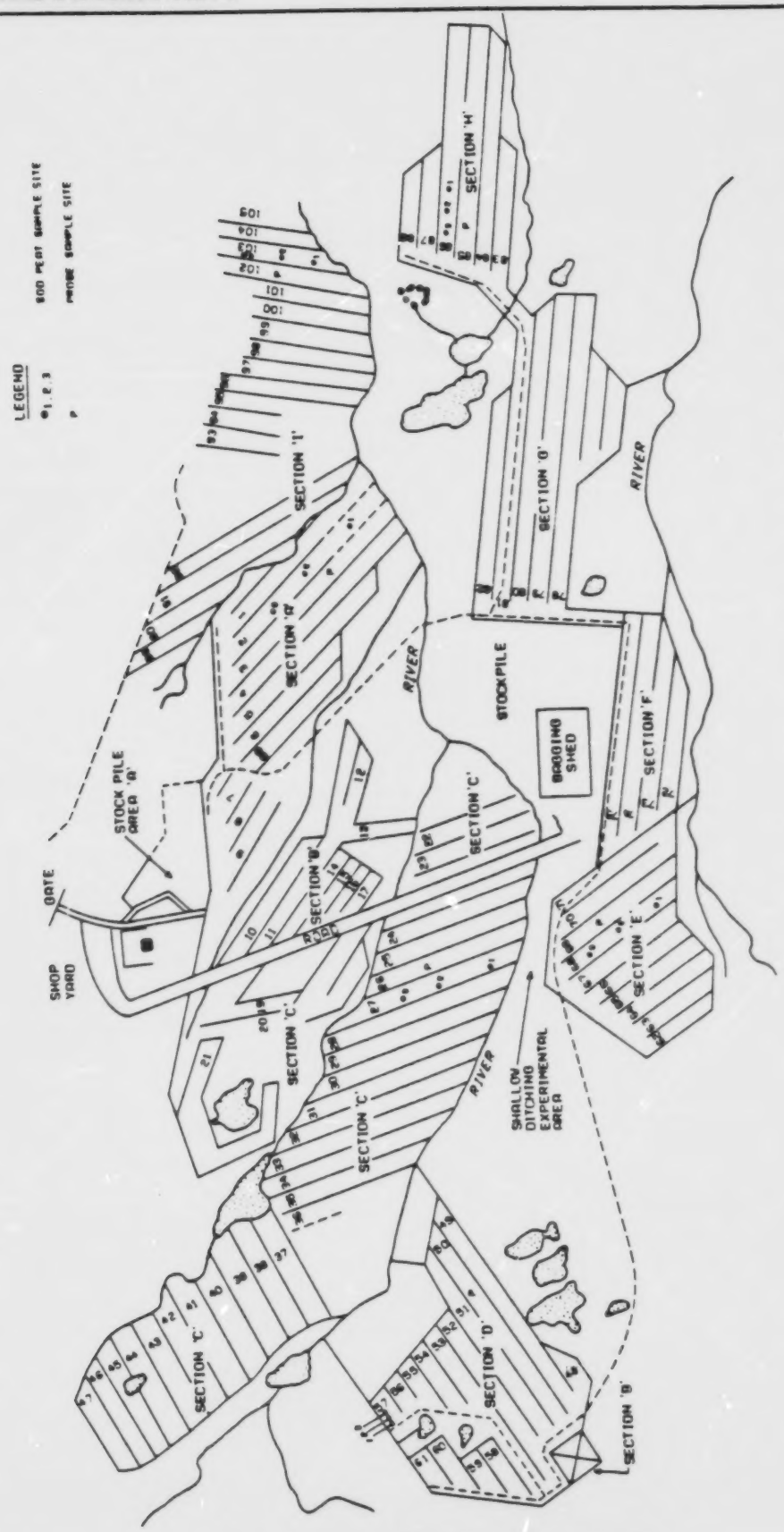


Figure 8 Layout of Peat Fields at St. Shotts

3.2.3 Methodology for Moisture Content Determination

Samples of the peat sods for moisture content determination were collected randomly from the same locations each day. Normally this was from the center of the peat fields since it was determined that the sample would be more representative than samples taken nearer the drainage ditches. A complete cross section was taken near the center of each sod and placed immediately in a covered foil container to prevent moisture loss. The wet weight was then determined within a few hours of collection and the samples dried for 36-48 hours at a temperature of 105°C. The dry weight was then determined and the sample moisture content of the sample calculated using the following formulas.

$$\% \text{ moisture content (wet basis)} = \frac{\text{wet weight - dry weight}}{\text{wet weight}} \times 100$$

$$\% \text{ moisture content (dry basis)} = \frac{\text{wet weight - dry weight}}{\text{dry weight}} \times 100$$

Normally the sampling of the peat sods began shortly after extrusion (early June) and continued until harvesting (August or September).

3.2.4 Results and Discussions

One of the objectives of this experiment has been to evaluate and compare the peat sod drying pattern of two extrusion methods (i.e. field press, super cutter). A further initiative was to consider these drying rates in association with various climatic factors (i.e. rainfall, wind speed, air temperature).

The field press sods clearly exhibit an accelerated drying rate relative to that of the super cutter. Data collected in 1987 and 1988 reflect this pattern; during each year sods of both types were exposed to the same weather conditions. The only other variable was the ground drying surface. On June 15, 1987 both sod types had a moisture content (wet basis) of approximately 86%. The field press sods dried more quickly than the super cutter product, yielding moisture contents of 60.1% and 75.6% respectively on July 6, 1987. This is shown in Figure 9. The weekly water loss for both sod types (1987, 1988) is presented in Figure 10. This is found by firstly determining the actual volume of water loss on a weekly basis and presenting it as a percentage of total water loss over a known drying period (e.g. June 15 - July 6, 1987; June 15 - August 25, 1988) (see sample calculation).

Sample Calculation: (Super Cutter, 1987)

Date	June 15	June 22
MC%	86.0	80.8

$$\text{Residual Water (units)} = \frac{(100 - \text{MC\% original}) \times (\text{MC\% new})}{(100 - \text{MC\% new})}$$

$$= \frac{(100 - 86.0) \times (80.8)}{(100 - 80.8)}$$

$$= \frac{14 \times 80.8}{19.2}$$

$$= 58.9$$

Water Loss (units) = MC% original - Residual Water
= 86.0 - 58.9
= 27.1

Weekly Water Loss(%) = (%)Water Lost / MC% original

= 27.1 x 100 / 86.0
= 31.5%

In 1987 the super cutter sods experienced the highest proportion of their overall loss during the first week after extrusion and showed a marked decline over the next two weeks (Figure 9). This contrasted with the field press sods which showed a consistent loss in moisture content during the same period. Figures 11 and 12 present data for the wetter 1988 season, again showing the accelerated drying rates of field press sods relative to the super cutter product. For the period from June 15 to August 24 the moisture content of the field press sods fell from 86.3% to 53.3% representing an actual water loss of 81.9%.

At the same time the super cutter sods moisture content dropped from 83.8% to 68.6% for a water loss of 57.8%. This persisting trend clearly outlines the effect of drying surface on peat sod drying rates. The relatively wetter fields serve to retard the drying rate, all other things being equal.

Definitive patterns were identified in relating drying rate to levels of rainfall for both extrusion methods. Data for both years (1987; 1988) were again analyzed on a weekly basis and exhibited a general trend of decreased moisture loss with increased rainfall. During the relatively dry weather conditions of 1987, both sod types showed very high initial drying rates which subsequently corrected in response to periods of elevated rainfall. This reactive drop in moisture loss was more pronounced with the super cutter sods which saw only a slight decrease in moisture content from 80.8% to 75.6% over the next two weeks. This contrasts with the field press sods which experienced a decrease from 80.6% to 60.1% over the same time period (Figure 9). During 1988 the reverse was true with the field press sods showing a comparatively lower level of moisture loss (on a seasonal percentage basis) in response to a sustained period of rainfall. The weeks of July 20 and 27 received rainfall levels greater than 40 mm. The field press sods reacted more strongly with weekly moisture losses declining from 29.1% to approximately 4-5% before correcting above the 6.0% level six weeks later (Figure 10). This reaction was much less prominent for super cutter sods with a trend correction evident after two weeks.

No relationship was found between drying rate and average wind speed. This is not unexpected since periods of relatively higher mean wind speed were associated with incidents of high and low rainfall levels alternately. This implies that wind speed must be combined with a specific influence (e.g. higher air temperature, decreased humidity) to effect an increase in drying rate. No data are available however on daily air temperature schedules or relative humidity levels at the study location, thereby precluding such interpretation.

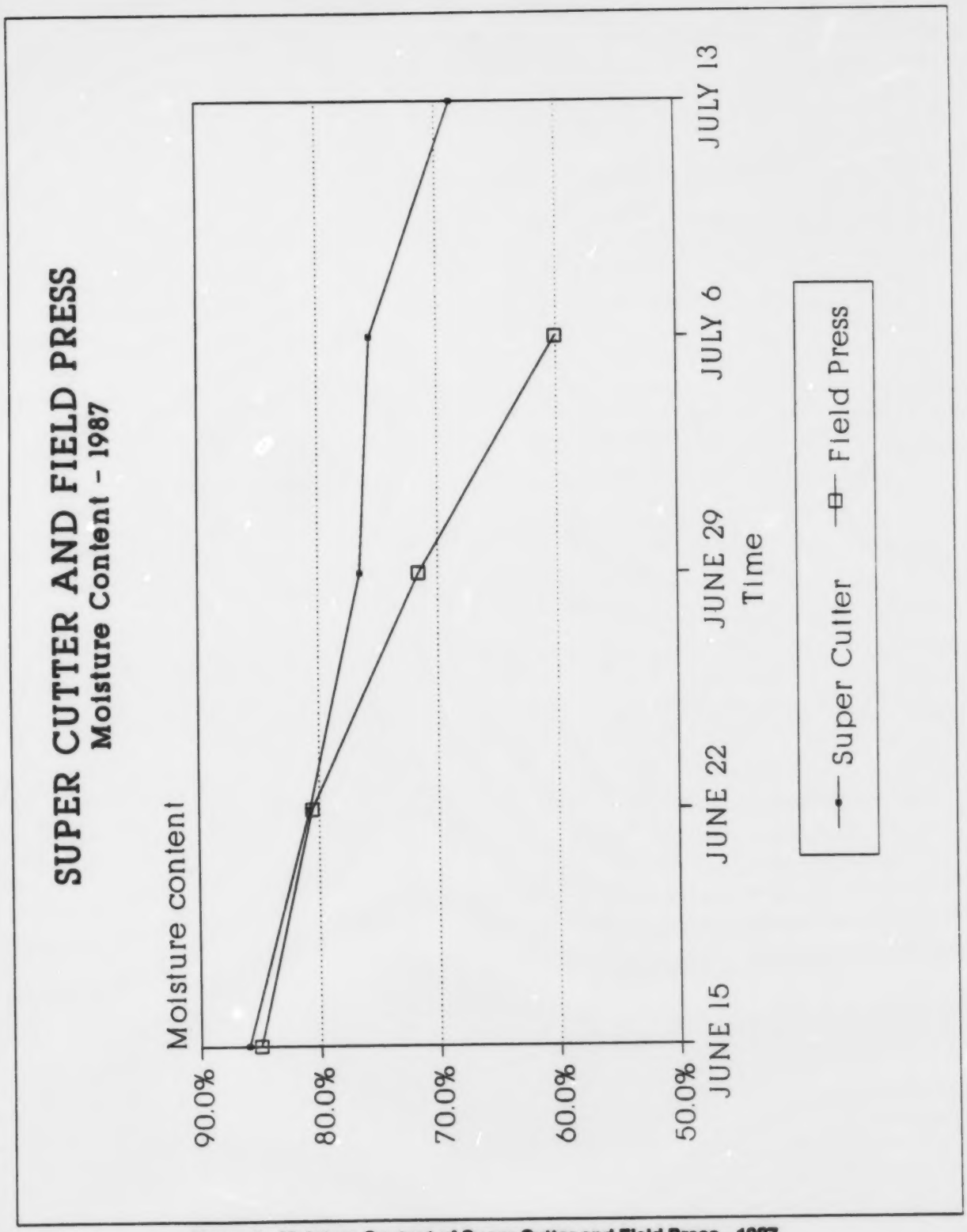


Figure 9 Moisture Content of Super Cutter and Field Press - 1987

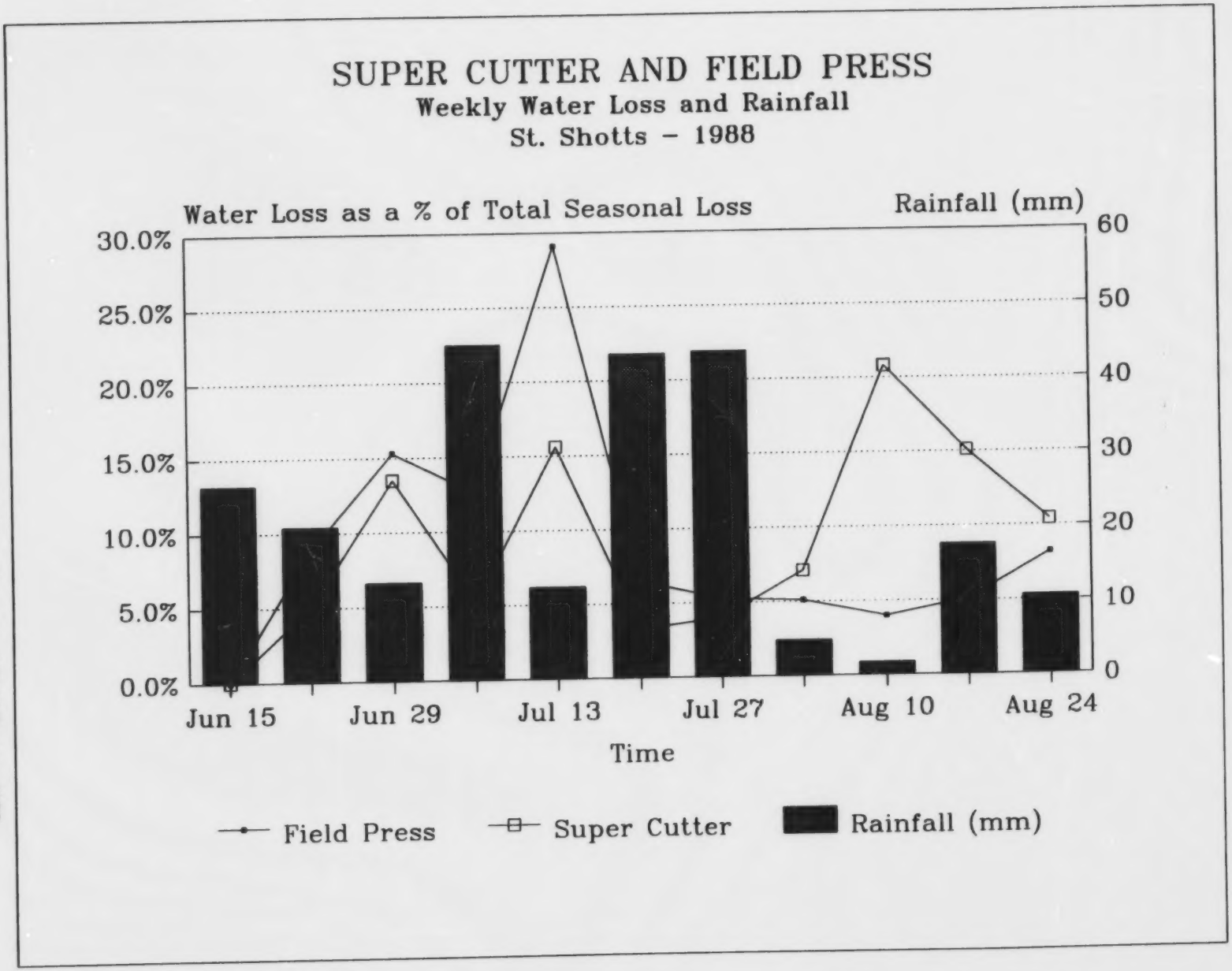


Figure 10 Weekly Water Loss - Super Cutter and Field Press - 1988

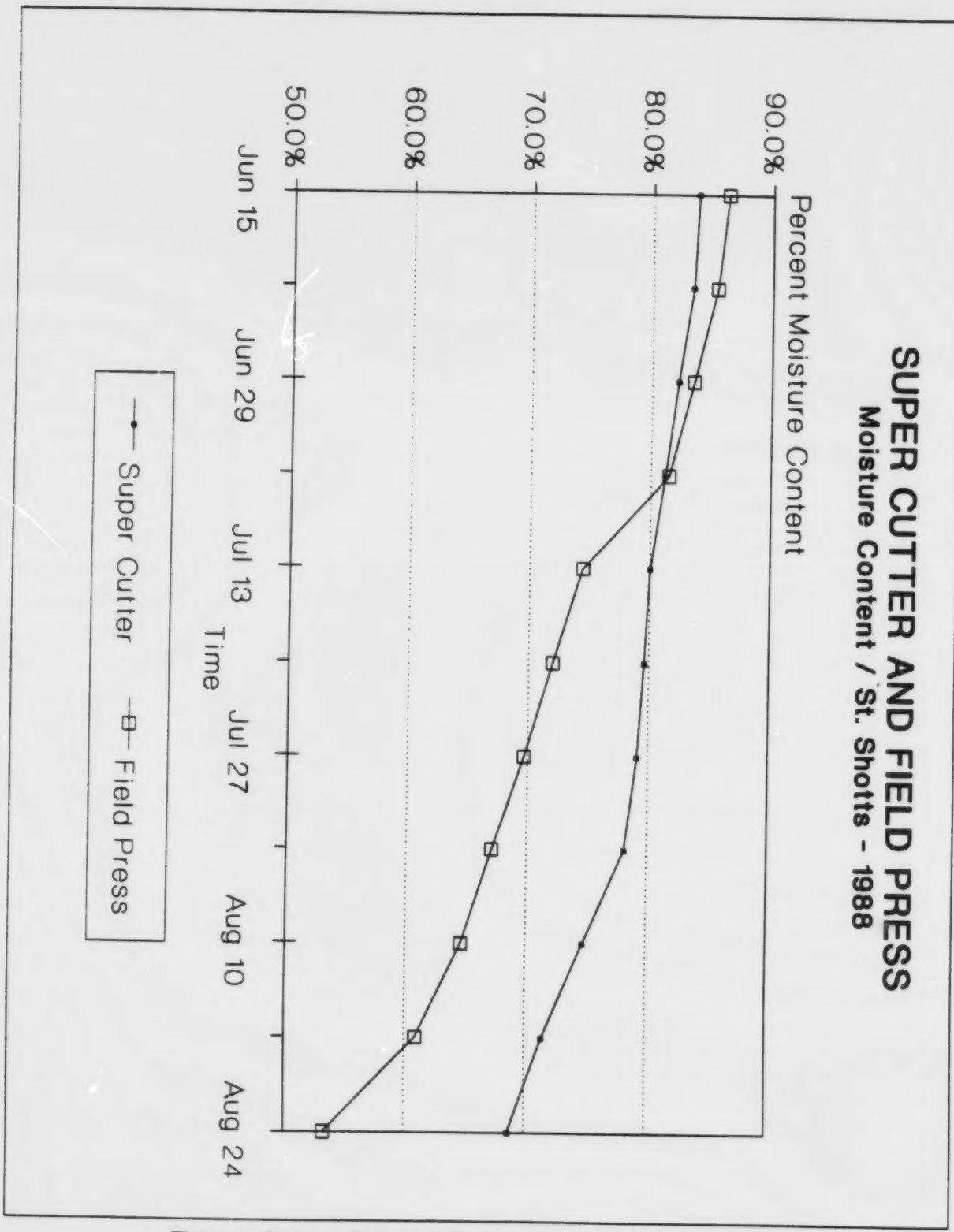


Figure 11 Moisture Content of Super Cutter and Field Press - 1988

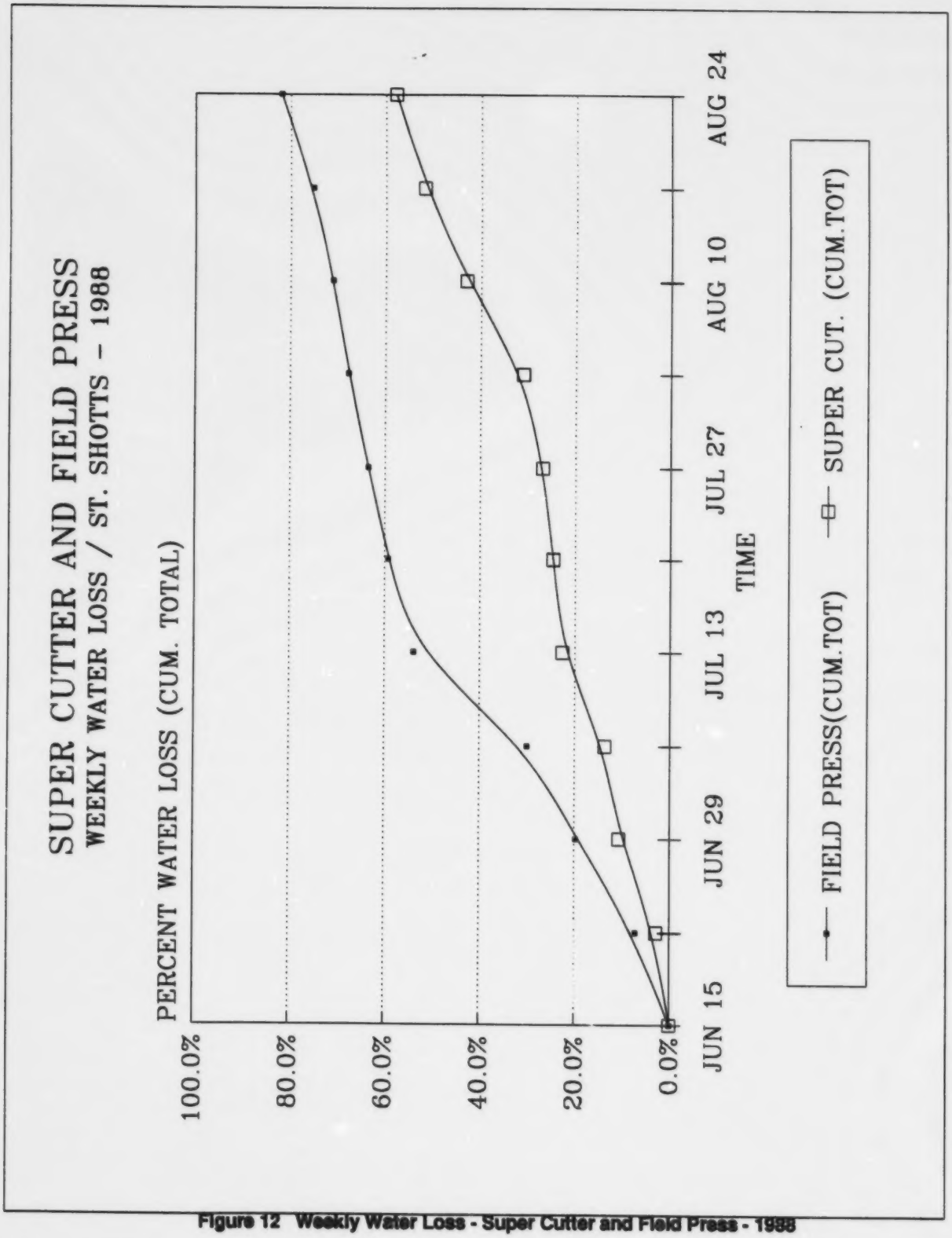


Figure 12 Weekly Water Loss - Super Cutter and Field Press - 1988

4.0 MONITORING PROGRAM - PART B

4.1 Introduction

The blanket bogs at St. Shotts began developing 5000 years ago (Davis 1989) in response to prolonged saturation of the soil. The saturation may have arisen due to a high regional water table, a locally perched water table overlying low permeability sediments, or as a result of ground water seepage toward the surface (Mulqueen 1986). Local well records (unpublished data) show a steeply sloping water table near the coast, adjoining more gently sloping water tables in the upland blanket bogs. These conditions preclude a general upward seepage of groundwater to this area. Perched water tables may occur in some blanket bog locations but generally it appears to be the climate, which is sufficiently wet enough to produce the high regional water table found in the area of St. Shotts, that has created the blanket bogs in this area.

In order for peatland development to proceed on a commercial scale it is essential to drain the peat deposit. The aim of drainage is to lower the water table, thus lowering the moisture content of the surface layer of peat, which in turn increases the bulk density and the bearing capacity of the peat surface. To accomplish this, it is necessary to lower the ground water level to the extent that the capillary rise of water to the peat surface will be reduced (Paivanen 1980). Mulqueen (1986) states that the objective of drainage is to lower and hold the groundwater sufficiently deep to meet the requirements for subsequent development and utilization by opening stable drains to allow for discharge of water and rainfall. Ditching lowers the water table and increases decomposition so that the physical properties of the peat change, bulk density increases and the macro-pore space and permeability decreases (Verry and Boelter 1978). In order to understand the changes we must have a general understanding of the *in situ* peat.

The peat is formed in two distinct layers; the upper layer (usually 10-30 cm) forms the acrotelm (Ingram 1983) where the living, dead and undecomposed vegetation has large pores, thus high specific yield and hydraulic conductivity (Boelter 1972). This layer is responsible for most of the water flow in peatlands. The layer of decomposed and decomposing peat below the acrotelm is called the catotelm (Ingram 1983) which has a much lower specific yield, and hydraulic conductivity (three orders of magnitude less). The catotelm represents a considerable water storage volume but in undrained peat this water is generally immobile.

A drainage experiment in a Minnesota peat bog (Boelter 1972) showed that ditching effectively drained the acrotelm, but had little effect on the catotelm beyond 5 m from the ditch. Burke (1961) also showed this to be especially true in blanket bogs in Ireland and recommended a ditch spacing of 3.65 meters to effectively drain these deposits. This small ditch spacing creates a steep enough hydraulic gradient to partially offset the lower transmissivity of catotelm peat.

The objective of this section of the report is to describe the monitoring program and to evaluate the hydrological response of the St. Shotts site to two years of drainage and the Markland site to one year of drainage. The water table level and *in situ* soil moisture content of drainage fields with 5, 10, and 20 meters ditch spacing are analyzed and compared to two simple theoretical drainage methods.

4.2 Moisture Content of the Surface Peat Layer

It can be seen from the climatic data presented in Section 3.1 that the southern Avalon has a severe climatic environment for peat harvesting. This area of the province has excessive rainfall, and a low number of sunshine hours. These factors often result in a high water table in the peat deposits. This leads to a loss of stability of the peat surface and reduces the trafficability of the deposit. It is a well established fact that conventional peat production techniques demand that one of the first requirements is a well drained field with a firm drying surface. This is necessary to permit a highly mechanized operation for producing, turning, drying and harvesting of the peat fuel. A measure of determining whether or not a particular peat deposit is suitable for peat production to begin is the moisture content of the surface layer. In Ireland the surface layer of a drained peatland must have a moisture content of 80-82% before peat production is allowed to begin. (Information obtained during a 1986 visit to Ireland and discussions with the foremen of several large peat operations).

4.2.1 In situ Peat Moisture Content Monitoring Program

In 1986, the first year of the project, the surface layer of peat was sampled to a depth of 25 cm. Using a Hiller peat sampler, samples were collected at three locations at the center of each of the 5, 10, and 20 meter wide fields. Samples were taken on a daily basis during 1987 and analyzed during the winter. However, results from this first year of samples proved to be inconclusive in that there was no apparent change in moisture content in the first 25 cm, even after heavy rain. Upon further examination it was concluded that the Hiller sampling method was not accurate enough for our purposes. It appeared that too much water loss occurred in the collection of the sample and thus the results were inaccurate. Based on this assumption, the sampling procedure was changed for the 1987 and 1988 seasons. In these years the peat samples were collected manually by cutting a small trench and collecting three samples, one from the 0-10 cm layer, one from the 10-20 cm layer and one from the 20-30 cm layer. It was felt that by sampling from each of the three layers, as opposed to one composite sample, more reliable results would be achieved. Moisture content analysis were carried out on the samples using the same procedure as described in the sod peat drying tests (Section 3.2.3).

4.2.2 Results and Discussions of the in situ Peat Moisture Contents

The *in situ* peat moisture content data for both the St. Shotts site (1987 and 1988) and the Markland site (1988) are presented in a series of graphs at the end of this section.

St. Shotts Site (1987 and 1988)

Figure 13a % M.C. 0-10, 10-20, 20-30 cm layers - 5 meter field (1987)

Figure 13b % M.C. 0-10, 10-20, 20-30 cm layers - 10 meter field (1987)

Figure 13c % M.C. 0-10, 10-20, 20-30 cm layers - 20 meter field (1987)

Figure 14 % M.C. 5, 10, 20 meter fields, 0-30 cm layers (1987)

Figure 15a % M.C. 0-10, 10-20, 20-30 cm layers - 5 meter field (1988)

Figure 15b % M.C. 0-10, 10-20, 20-30 cm layers - 10 meter field (1988)

Figure 15c % M.C. 0-10, 10-20, 20-30 cm layers - 20 meter field (1988)

Figure 16 % M.C. 5, 10, 20 meter fields, 0-30 cm layers (1988)

Figure 17 % M.C. 5, 10, 20 meter fields, 20-30 cm layers (1987)

Figure 18 % M.C. 5, 10, 20 meter fields, 20-30 cm layers (1988)

Markland Site (1988)

Figure 19a % M.C. 0-10, 10-20, 20-30 cm layers - 5 meter field (1988)

Figure 19b % M.C. 0-10, 10-20, 20-30 cm layers - 10 meter field (1988)

Figure 19c % M.C. 0-10, 10-20, 20-30 cm layers - 20 meter field (1988)

Figure 20 % M.C. 5, 10, 20 meter fields, 0-30 cm layers (1988)

It can be seen from the above list of figures that there are many combinations of ways to present the data. The intention here is to present the data in such a way that comparison can be made between the moisture contents of the various peat layers (0-10, 10-20, 20-30 cm) on the various fields (5, 10, 20 meter). In the case of the St. Shotts site, the data are presented for two years, 1987 and 1988, (see figures 13-18) which represent one and two years after drainage. Data for the Markland site is for 1988 and represents one year after drainage (see figures 19 and 20).

The peat moisture content showed a rapid initial decline. The average moisture content at the 20-30 cm level dropped from 88% in the undrained condition, to 85% in the first year following drainage (see table below).

Moisture content at 20-30 cm

Date/location	Moisture Content (%)
Undrained Bog	88.0
Jun & Jul 1987	86.5
Aug & Sept 1987	85.0
Jun & Jul 1988	84.8
Aug & Sept 1988	84.8

As expected, the 5 meter drainage field had the lowest moisture content. This can be seen when we compare the moisture content of the 20-30 cm layer on each of the fields for both 1987 and 1988 (figures 17 and 18). The 10 and 20 meter sites were correspondingly higher.

When we compare the data from the St. Shotts site for the years 1987 and 1988, we have some interesting observations. A moisture content of 82-84% was achieved in all sites by the end of the 1987 season (a much drier than normal summer). The low water table and negative pore water pressures in the considerably thick unsaturated zone probably resulted in subsidence and densification of the peat (Mulqueen 1987), with a concomitant decrease in the moisture content. There was only partial recovery in 1988, when average conditions occurred. The particularly dry conditions in 1987 probably accelerated the densification process.

Further examination of the moisture content at 0-10, 10-20, and 20-30 cm at the 5 and 20 m drainage fields reveals evidence of the drainage effectiveness (figures 15a, 15b, and 15c). At the 20 m ditched site the moisture content was highest near the surface. This is similar to undrained bog, where large open pores and uncompacted vegetation contain a high proportion of water when saturated. Where drainage has been most effective (i.e. in the 5 m fields), the surface pores have been largely drained as they have little capillarity to hold water against gravity. This has resulted in a reversal of the moisture content - depth relation, so that in well drained sites the upper layers have the lowest moisture content. That the moisture content is highest in the upper layer of the 20 metre field clearly indicates the insufficiency of 20 metre ditch spacing.

When making comparison of the data from the two years of drainage at the St. Shotts site it must be kept in mind that 1987 was an extremely dry year, while 1988 had an slightly higher rainfall than normal.

By comparing figures 16 and 20, we can see the difference in the moisture content of the *in situ* peat at the two sites. It can be seen that the moisture content for the 5 meter field at St. Shotts is between 82 and 84%, while at Markland the 5 meter field shows an average moisture content of 90 - 92%. A similar trend is evident in the 10 and 20 meter fields. It must be remembered that the Markland data is after one year of drainage and the St. Shotts data is after two years of drainage. As well, the 1988 data for St. Shotts were obtained after a very dry year in 1987 in which it can be assumed that the moisture contents were lower than would normally have been the case in a year with normal rainfall. The effect of the dry year can be seen by comparing figures 17 and 18: in 1987 there was much more variation in the moisture contents of the various fields than there was in 1988 where the trend is for the moisture contents in the various fields to be more uniform.

With only one year of data from the Markland site and two years from the St. Shotts site it is too early to say if the moisture content levels in the various width fields have reached equilibrium. Additional data collected over the next two-three years will provide the answer.

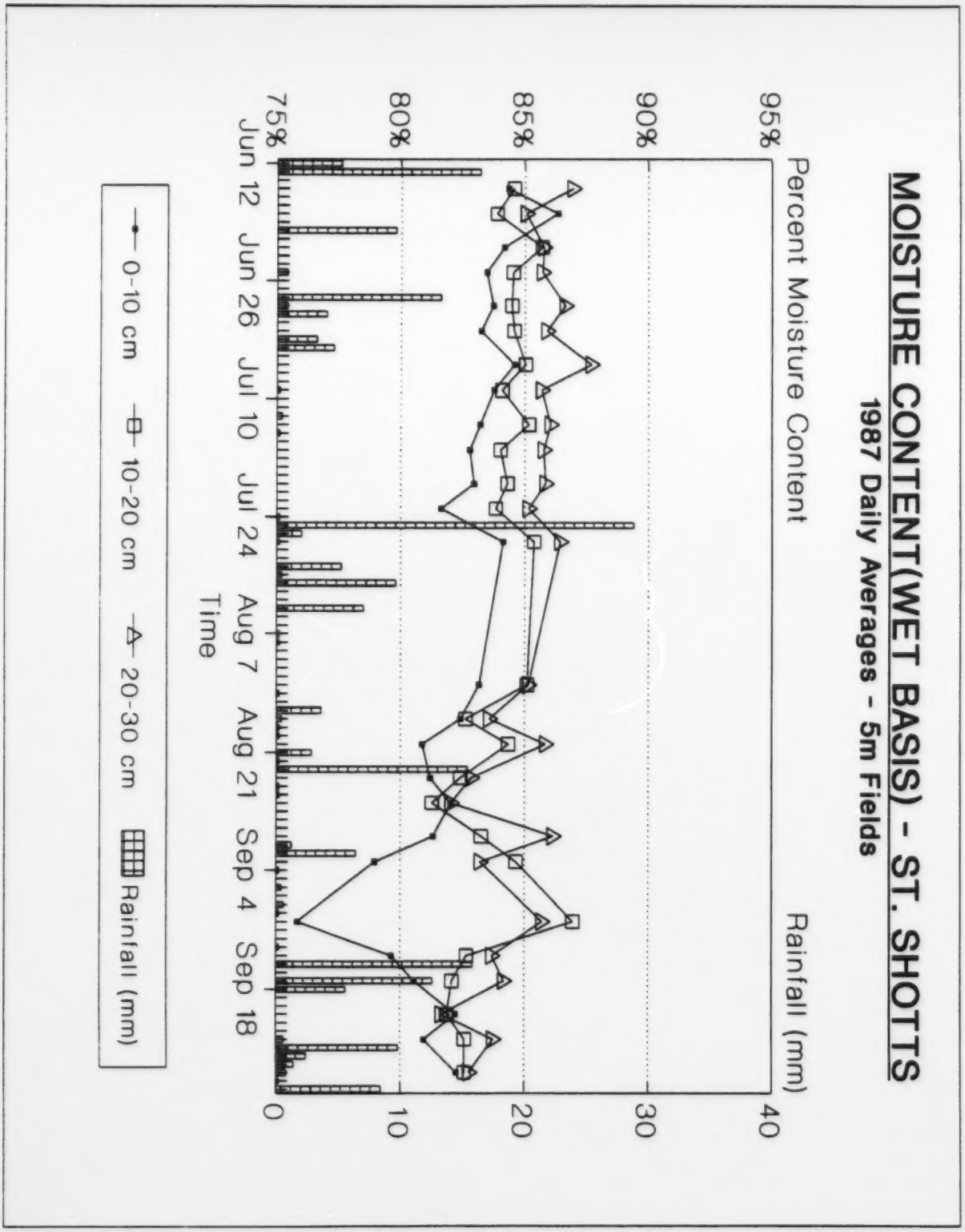


Figure 13(a) Comparison of the M.C. of the surface layers on a 5 meter field (St. Shotts, 1987)

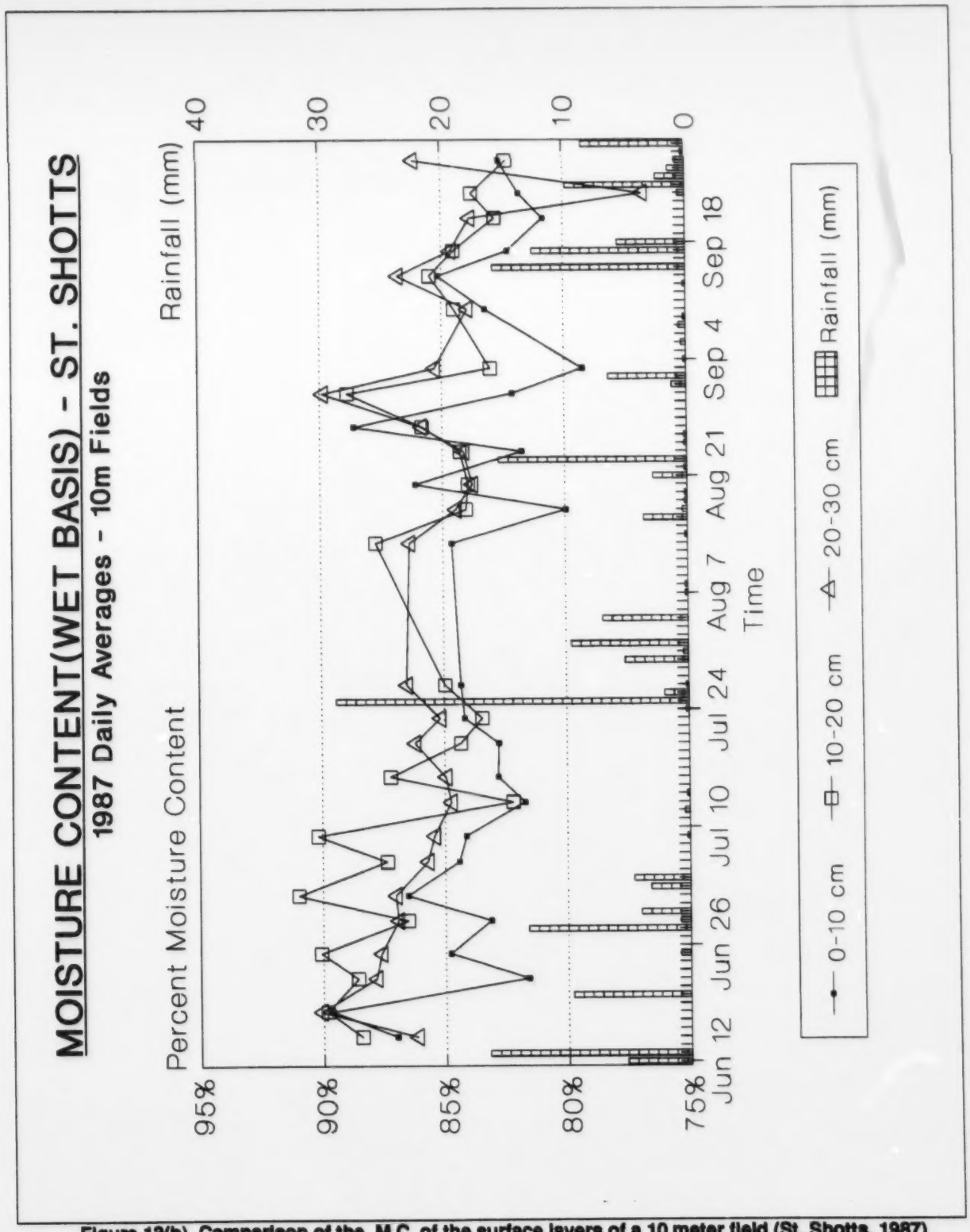


Figure 13(b) Comparison of the M.C. of the surface layers of a 10 meter field (St. Shotts, 1987)

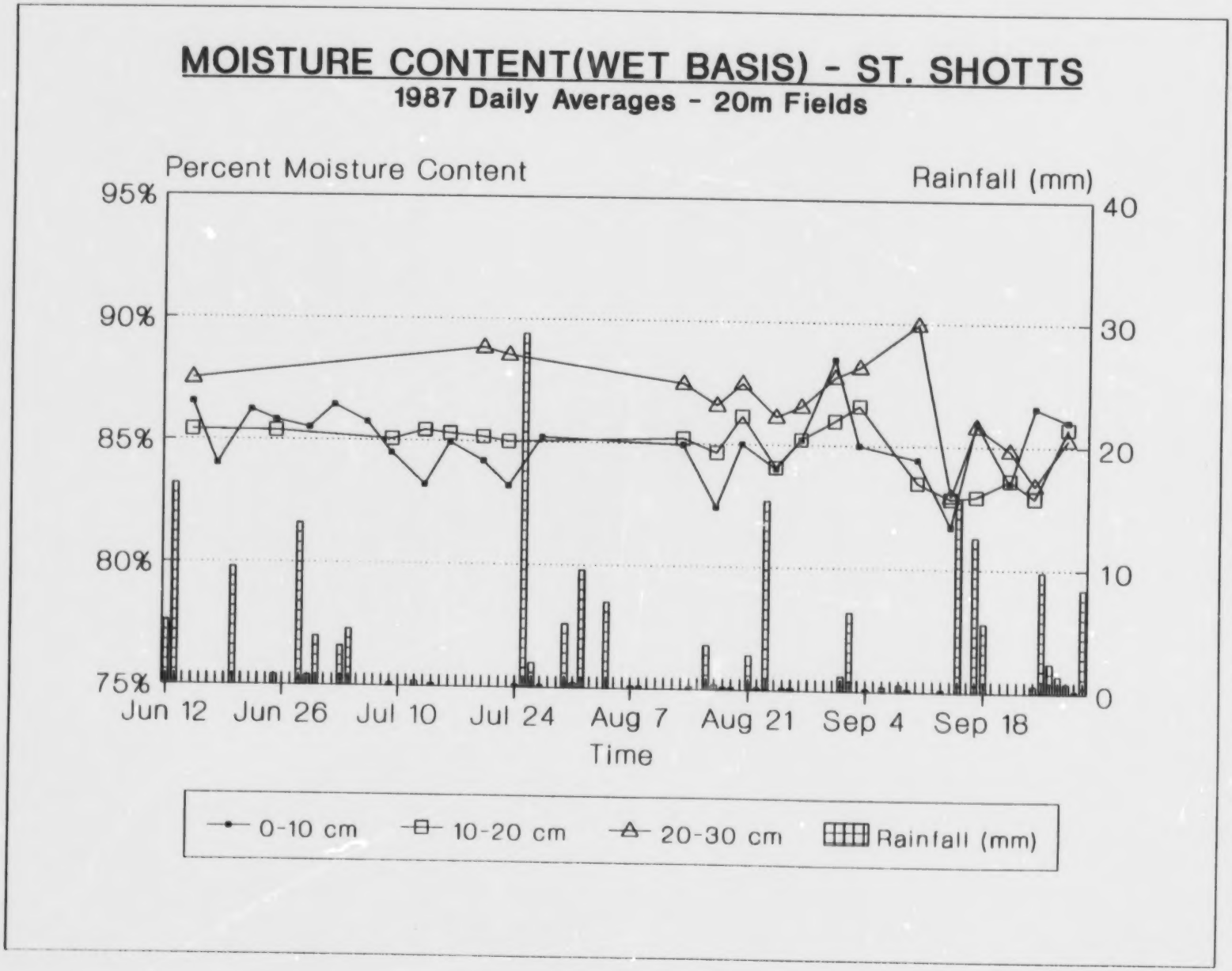


Figure 13(c) Comparison of the M.C. of the surface layers on a 20 meter field (St. Shotts, 1987)

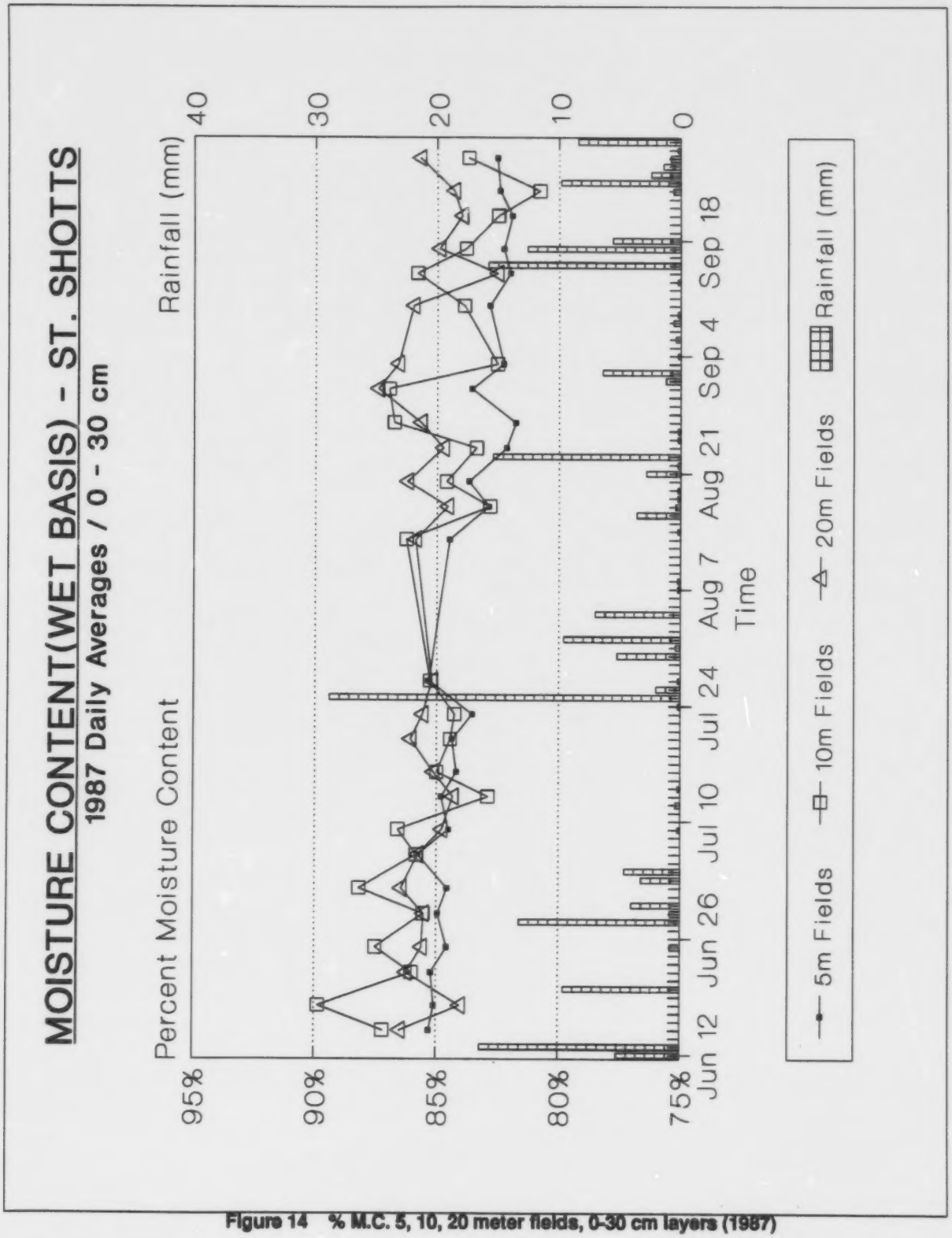


Figure 14 % M.C. 5, 10, 20 meter fields, 0-30 cm layers (1987)

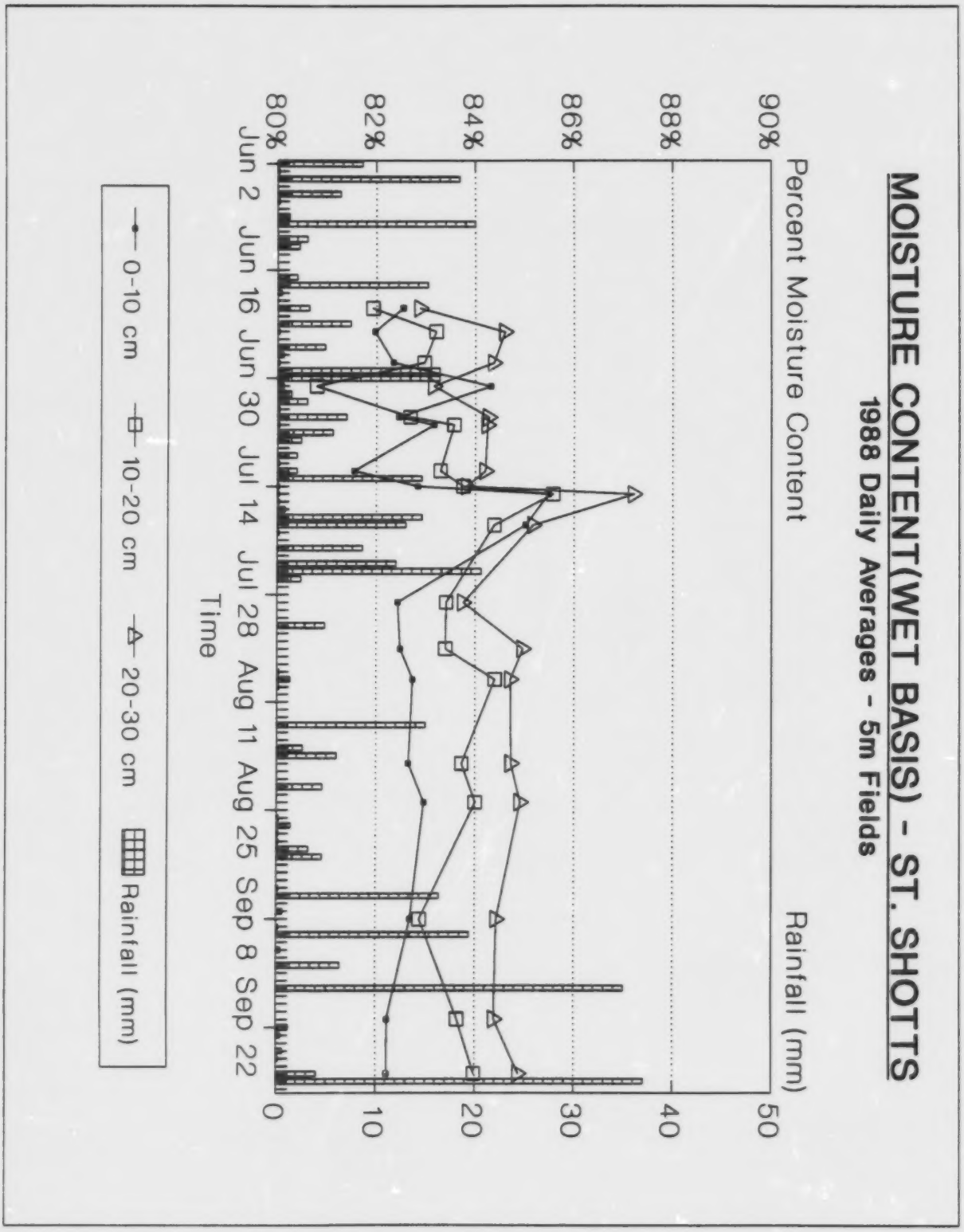


Figure 15(a) Comparison of the M.C. of the surface layers on a 5 meter field (St. Shotts, 1988)

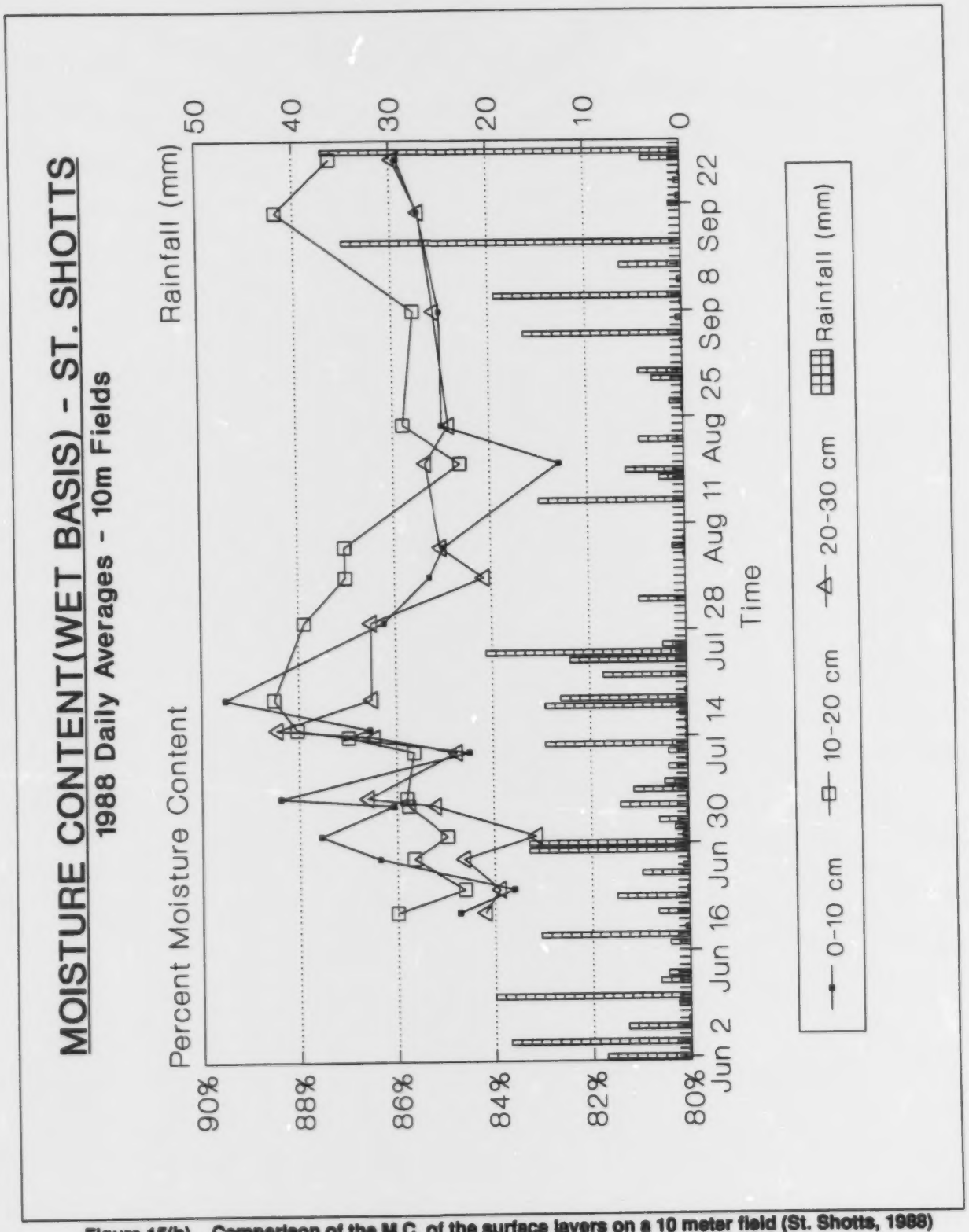


Figure 15(b) Comparison of the M.C. of the surface layers on a 10 meter field (St. Shotts, 1988)

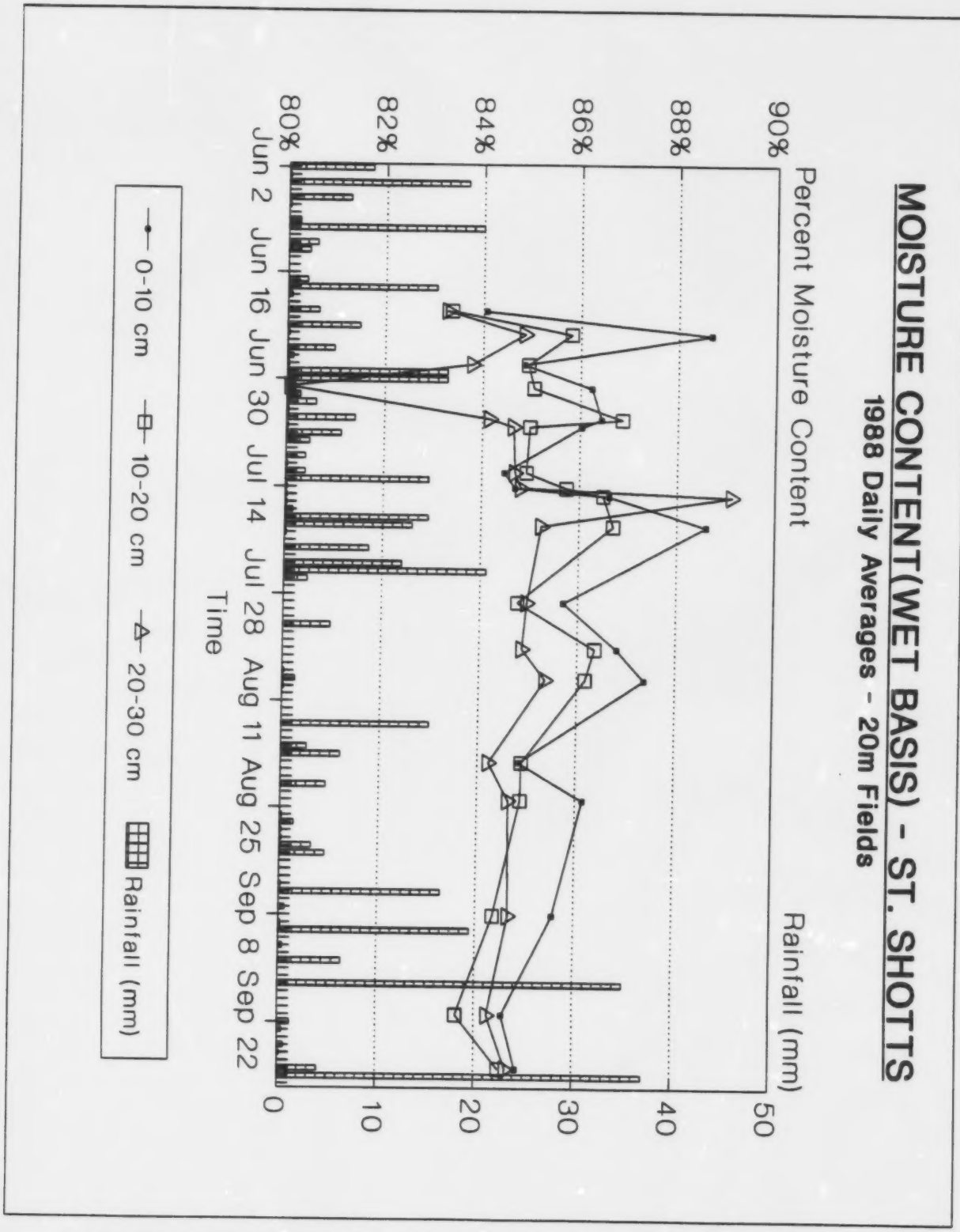


Figure 15(c) Comparison of the M.C. of the surface layers on a 20 meter field(St. Shotts, 1988)

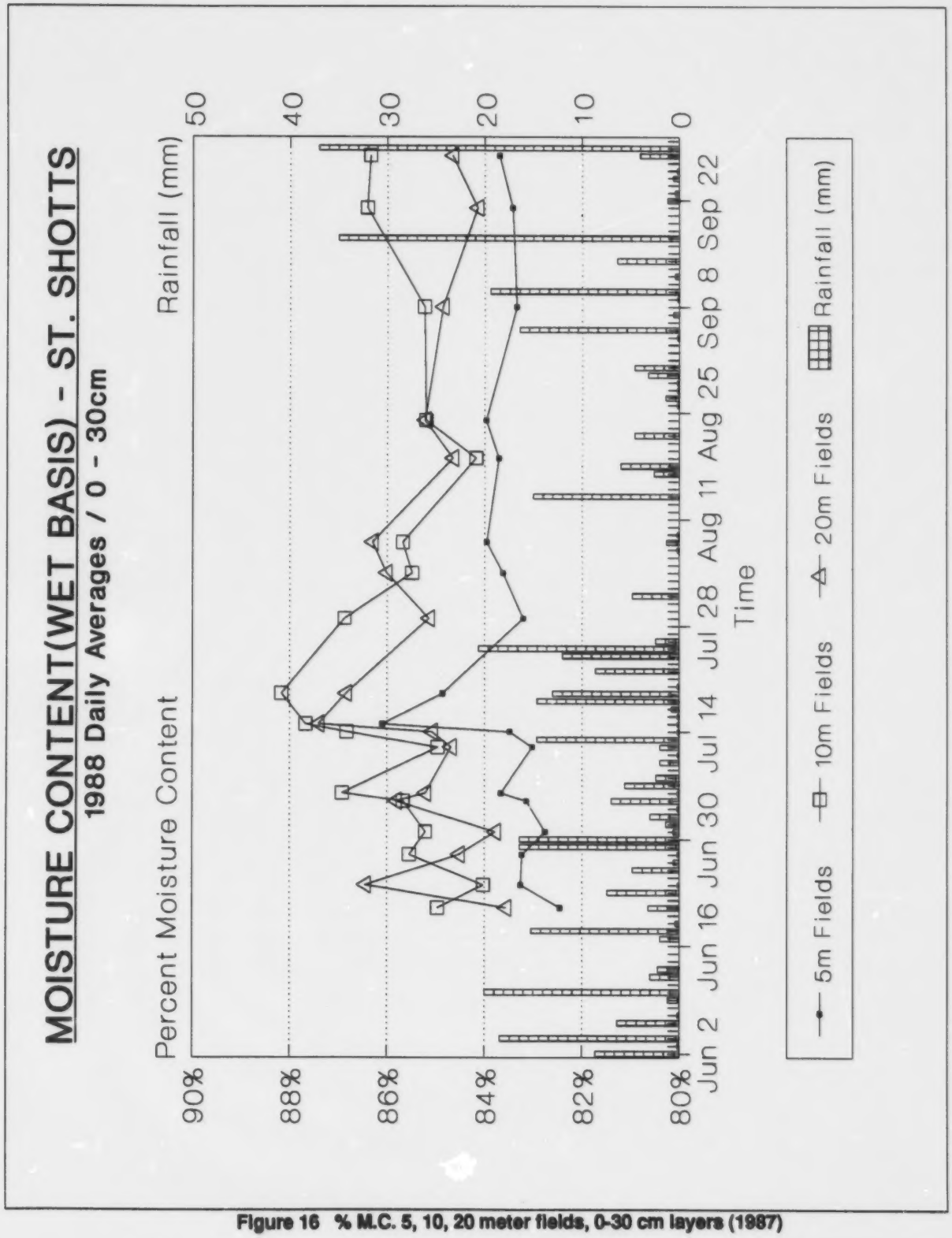


Figure 16 % M.C. 5, 10, 20 meter fields, 0-30 cm layers (1987)

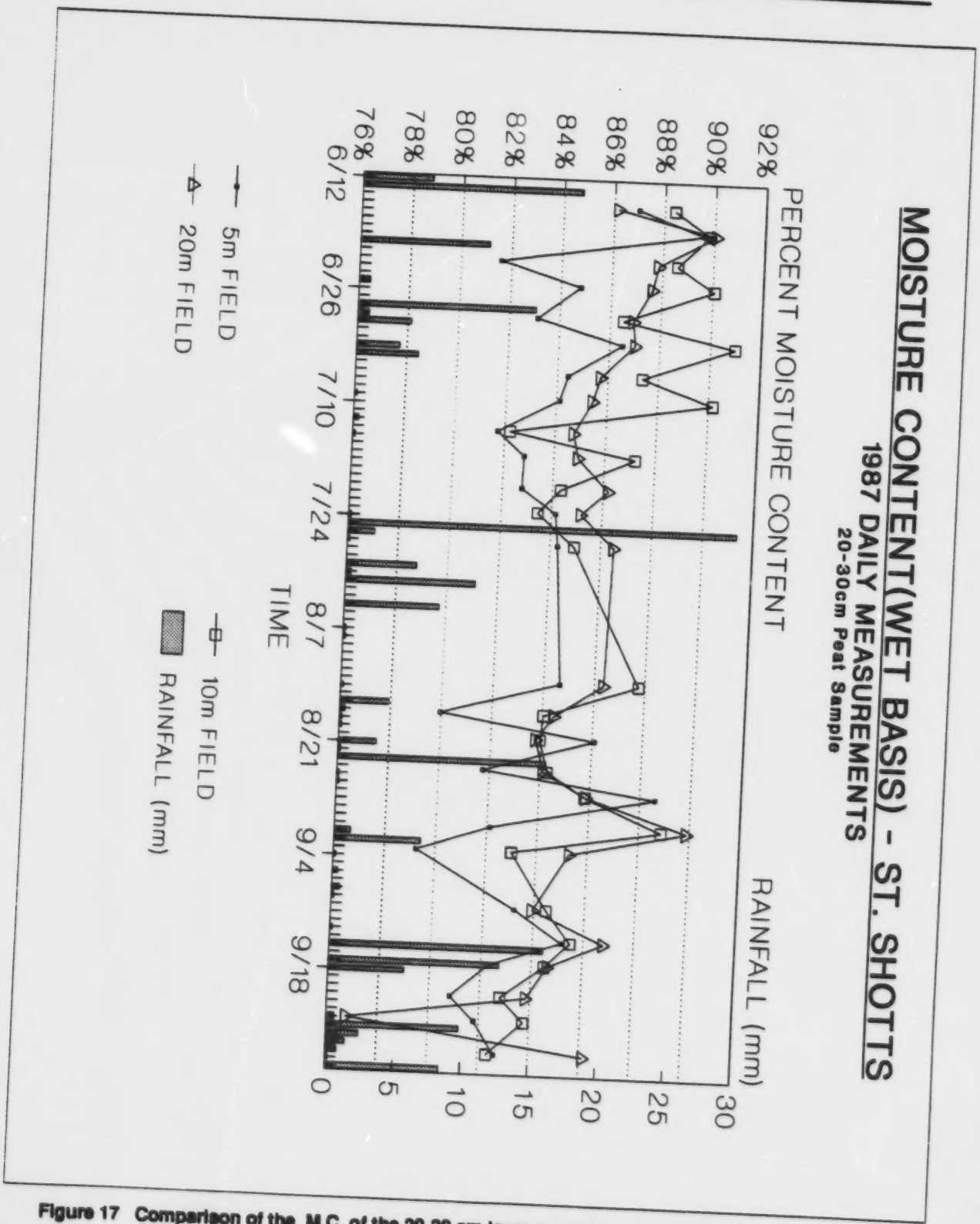


Figure 17 Comparison of the M.C. of the 20-30 cm layer on various width fields, (St. Shotts, 1987)

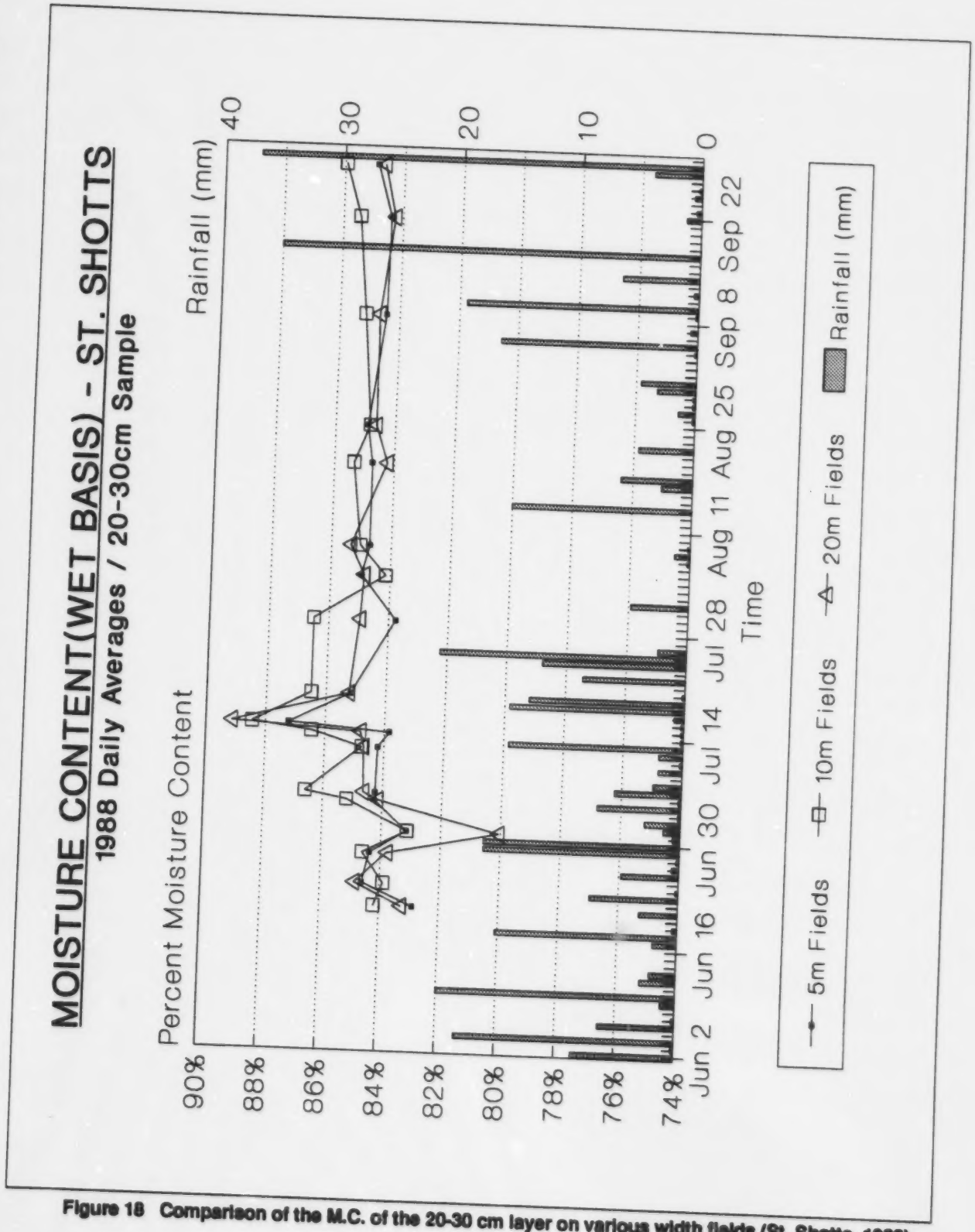


Figure 18 Comparison of the M.C. of the 20-30 cm layer on various width fields (St. Shotts, 1988)

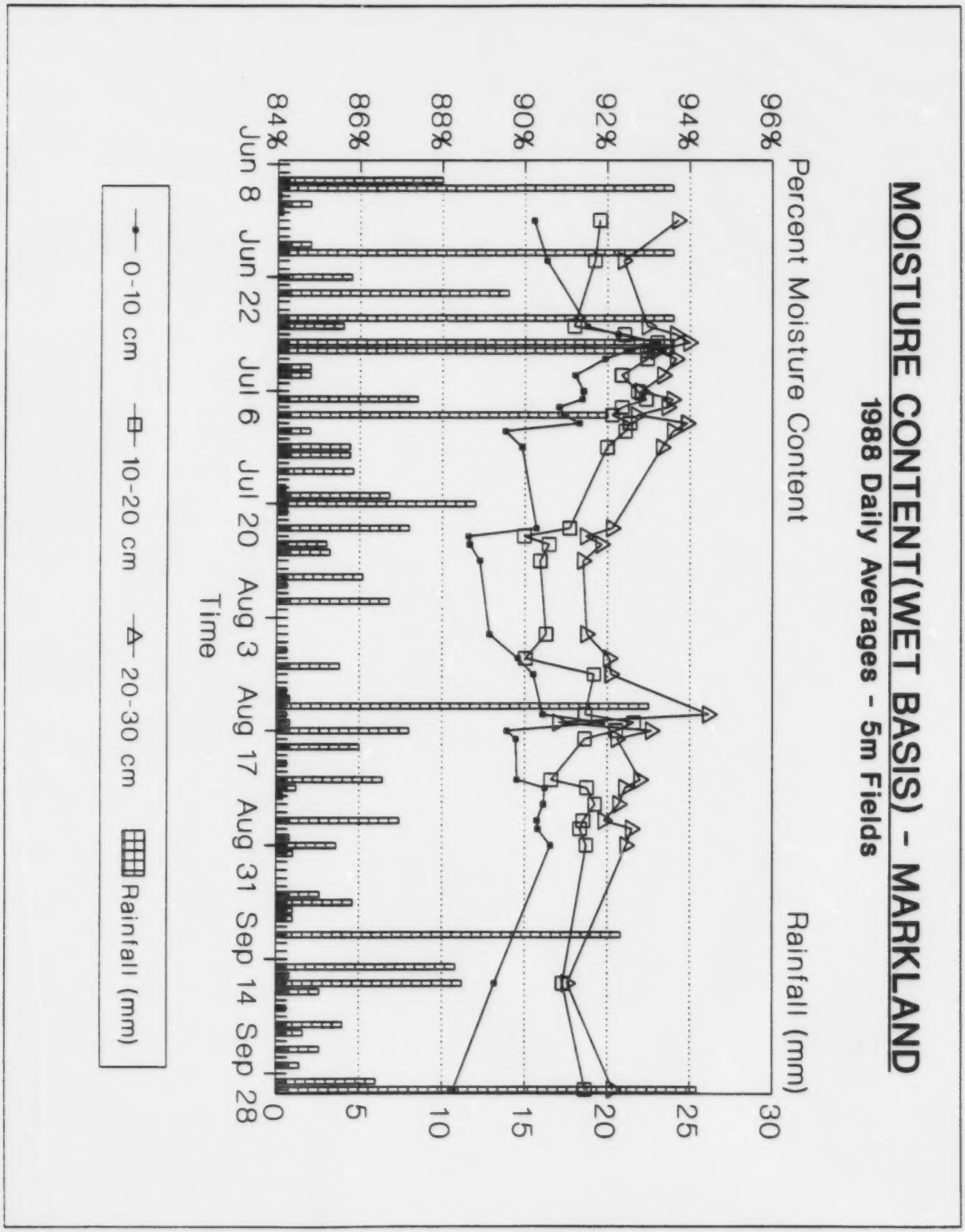


Figure 19(a) Comparison of the M.C. of the surface layers on a 5 meter field (Markland, 1988)

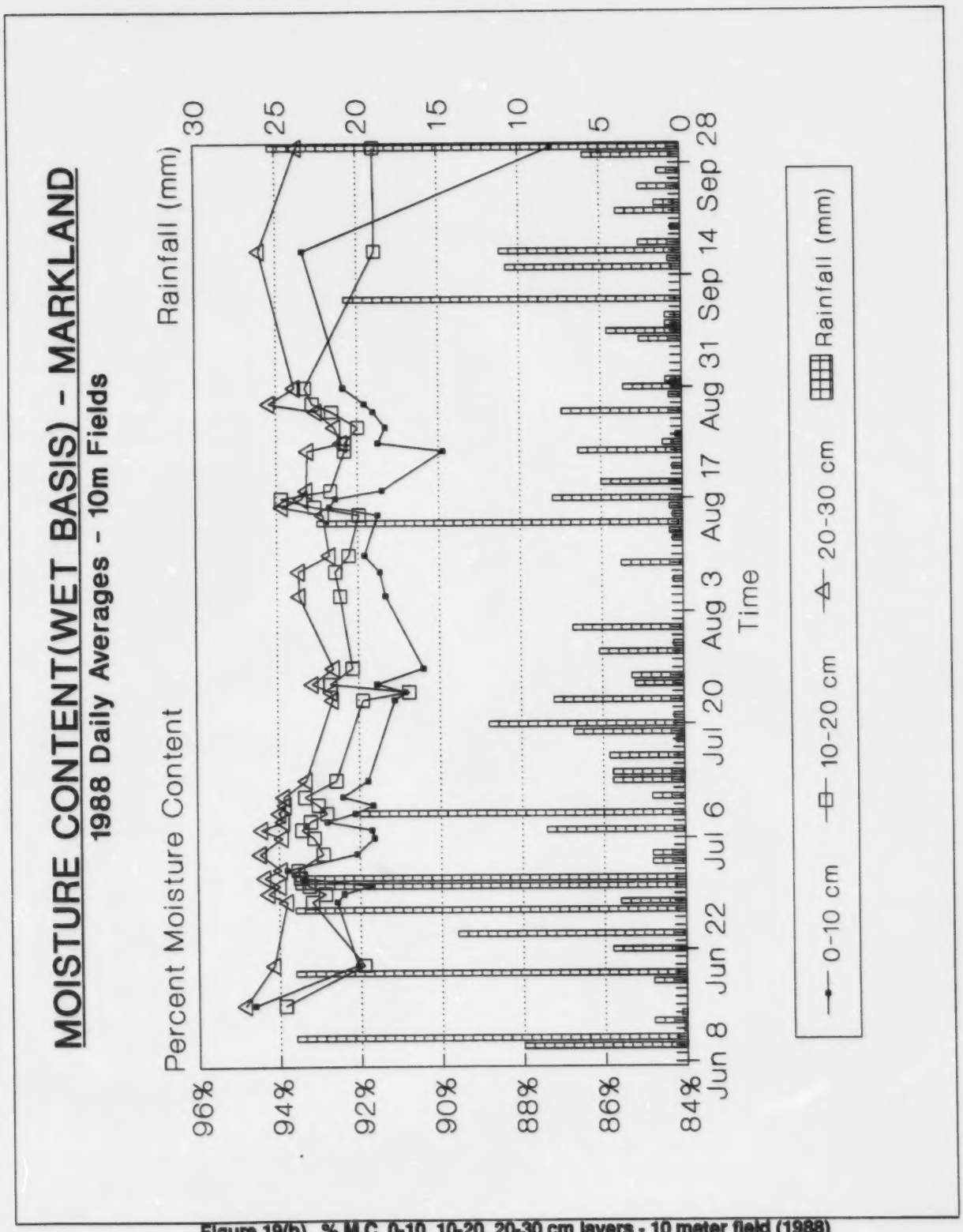


Figure 19(b) % M.C. 0-10, 10-20, 20-30 cm layers - 10 meter field (1988)

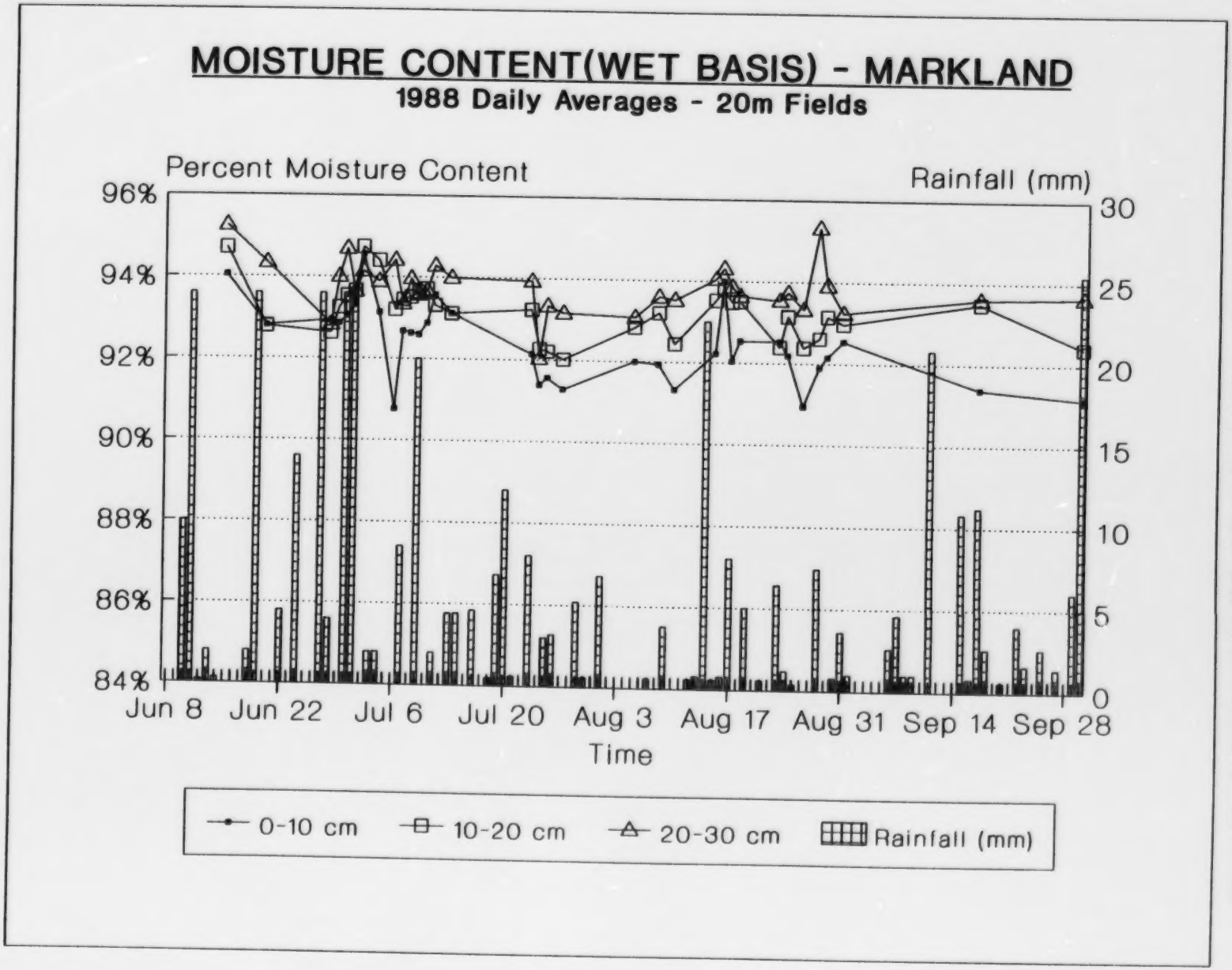


Figure 18(c) Comparison of the M.C. of the surface layers on a 20 meter field (Markland, 1988)

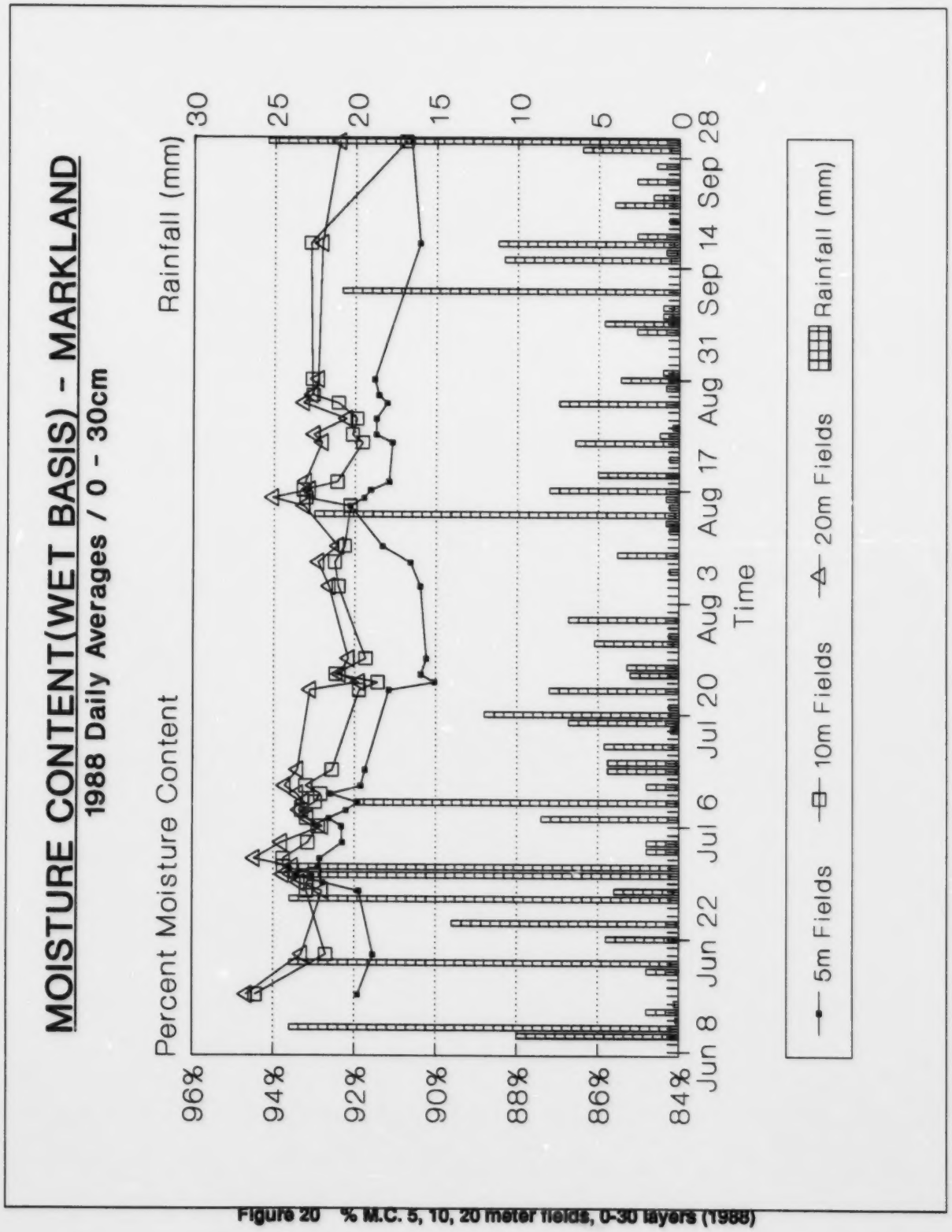


Figure 20 % M.C. 5, 10, 20 meter fields, 0-30 layers (1988)

4.3 Water Table Draw Down — Introduction

Wetlands represent a considerable store of water and organic material. Understanding the relationships that govern water storage in wetlands is the key to assessing their hydrological significance. In the acrotelm, water flow can proceed relatively rapidly because of the high hydraulic conductivity (Boelter 1972), and large changes in water storage can occur because the specific yield is high (Price and FitzGibbon 1982). In the catotelm, the low hydraulic conductivity severely limits the lateral transport of water. Even if flow were sufficient to lower the water table into the catotelm, only 10-15% of the water will be released because of the low specific yield (Price and FitzGibbon 1982). Thus the catotelm is effectively "dead storage", and water input, transmission and release does not readily occur (Ingram 1983). This has a marked influence on drainage. A bog hydrograph responds rapidly during periods of water excess, especially during and shortly after the snowmelt period, and in the autumn when precipitation exceeds evaporation (Bay 1969). During the wet periods the level of water storage is high within the acrotelm. Rain events during this period quickly cause the water table to rise in the acrotelm, sometimes above the surface, so the water can be transmitted rapidly to the ditches, which consequently experience sharp floods. The water drains easily from the acrotelm, and once the water table descends to the catotelm, drainage may cease entirely and the drainage can stop (Bay 1969). Further withdrawals of water are achieved only by evaporation.

4.3.1 Water Table Monitoring Program - Methodology

In 1986, a water table monitoring program was conducted at nine (three 5 metre, three 10 metre, and three 20 metre) of 25 field on an eight hectare site at St. Shotts. Stand pipes were installed at three locations (north end, south end and middle) along the center line of the nine fields. On three of the nine fields (one from each category) additional stand pipes were installed as follows:

5 meter field - 1 meter, 2.5 meters from the ditch

10 meter field - 1 meter, 2.5 meters and 5 meters from the ditch

20 meter field - 1 meter, 2.5 meters, 5 meters and 10 meters from the ditch.

An additional three pipes were installed in an undrained area.

In 1987, a second site of 5.2 hectares was ditched for drainage trials. This site was located at Markland on the center of the Avalon Peninsula (see Section 2.3 for site description and Figure 4). Fifty-four stand pipes were installed on the various width field, and an additional four pipes were located in the undrained area. Four fields each of the width (5, 10 and 20 meters) had stand pipes installed. As was the case at St. Shotts, the pipes were installed on the center of the fields at three locations. Also pipes were installed on one of each at a 5, 10, and 20 meter field to measure the lateral water table profile.

The water table in all the stand pipes were measured for the most part on a daily basis from June to October.

4.3.2 Results and Discussions of the Water Table Changes

The water table data for both the St. Shotts (1987 and 1988) and the Markland (1988) sites are presented in a series of graphs as follows:

Figure 21a Daily water table levels on a 5 meter field (St. Shotts, 1987)

Figure 21b Daily water table levels on a 10 meter field (St. Shotts, 1987)

Figure 21c Daily water table levels on a 20 meter field (St. Shotts, 1987)

Figure 22 Daily water table levels on all fields (St. Shotts, 1987)

Figure 23 Lateral water table profile on a wet and dry day (St. Shotts, 1987)

Figure 24 Lateral water table profile on a wet and dry day (St. Shotts, 1988)

Figure 25 Lateral water table profile on a wet and dry day (Markland, 1988)

Figure 26a Daily water table levels on a 5 meter field (St. Shotts, 1988)

Figure 26b Daily water table levels on a 10 meter field (St. Shotts, 1988)

Figure 26c Daily water table levels on a 20 meter field (St. Shotts, 1988)

Figure 27 Daily water table levels on all fields (St. Shotts, 1988)

Figure 28a Daily water table levels on a 5 meter field (Markland, 1988)

Figure 28b Daily water table levels on a 10 meter field (Markland, 1988)

Figure 28c Daily water table levels on a 20 meter field (Markland, 1988)

Figure 29 Daily water table levels on all fields (Markland, 1988)

4.3.2.1 Water Table Changes

The vertical profile of humification for the St Shotts blanket peat suggests that the thickness of the acrotelm is about 10-15 cm. This is important because the acrotelm has a higher hydraulic conductivity and specific yield. Therefore, the change in water storage, and the associated change in water table elevation (head) are non-linear with respect to depth. A unit change in head represents a smaller change in water storage where the specific yield is low, such as in the catotelm, than it does in the acrotelm where the specific yield is much higher (see table below). It is essential to recognize this when comparing water table fluctuations between sites.

Specific yield data, blanket bog near Cape St Mary's, 1989 (Price, Unpublished data).

Depth (cm)	Specific Yield
0-8	0.44
8-17	0.23
17-27	0.10
27-37	0.034
37-50	0.047
50-66	0.048

Following spring runoff in the first year after drainage (1987), a clear distinction developed between the water table elevation of the virgin bog (10 cm) and each of the 5, 10, and 20 m drainage fields (25 cm) (figures 21 and 22). This difference clearly demonstrates the immediate effect of ditching on lowering the water table. There was a marked decline in the water table in all drained sites in the dry period preceding July 25, but little decline occurred in the virgin bog, which suggests that drainage, rather than evaporation was dominant during this period. During these early stages of drainage, the water tables are making a rapid initial adjustment toward some new equilibrium condition, which will stabilize at a unique level depending on the values of the local hydraulic conductivity, specific yield, vertical water flux, and ditch spacing.

The rapid initial drainage which has occurred in all ditched sites can be explained through the transmissivity (T) of the peat deposit, where $T = Kd$, and where K is the hydraulic conductivity and d is the depth of the peat below the water table. In a two-layered soil where the acrotelm has a hydraulic conductivity 3 orders of magnitude greater than in the catotelm, outflow from the peat will be very rapid when the water table is high. However, once the water table drops into the catotelm, the net outflow will be greatly reduced. To induce significant groundwater flow rates in the catotelm, the water table gradient must be very steep, such as that produced by the 5 m ditch spacing. With 20 m ditch spacing, rapid drainage of the acrotelm is observed initially, but the hydraulic gradients are insufficient to effectively remove water from the catotelm. While the water table may be within the acrotelm in the 20 m field (figures 23-25), near the ditch the water table normally resides in the catotelm. Thus water draining from the acrotelm must pass through the catotelm to get into the ditch. Furthermore, because of the greater distance to the centre of the field in wider spaced drain fields, there is more water to be drained through the side of the ditch to produce a given water table decline. These factors have resulted in the early initial adjustment of the water table of drained sites.

On July 25 and 26 1987 there was 30 mm of rain which elicited only a 5 cm rise on the virgin bog and a 10 - 15 cm rise on the drained sites (figures 21 and 22). This is not unexpected, because the water table in the virgin bog was within the acrotelm, where the specific yield (S_y) is high. In the drained sites, the water table generally resided in the catotelm, so the larger water table decline represents an equivalent change in storage. For the remainder of July, August and early September, all sites experienced a further water table decline of about 20 cm. The parallel decline of the water table in the catotelm of each site indicates that evaporation dominated over drainage during this period, and that the rate of water loss was similar for all drained sites. It was perhaps somewhat greater for the virgin bog where water was more

readily available for evaporation. Increased rainfall and lower evaporation rates in late September allowed for complete recovery of the water table in the virgin bog. However, there was incomplete recovery in the drained sites, with progressively less occurring where the ditch spacing was narrower.

In the second year following drainage (1988), wetter than average conditions prevailed in June and average conditions occurred in July (figures 26 and 27). Distinct differences in water table elevation are again evident at all sites (Figure 27), however, several trends become apparent. The virgin bog, and 20 m and 10 m drained sites have relatively stationary water tables, which fluctuate between 5-10 cm, 10-20 cm and 20-35 cm respectively. The stationary feature indicates that an equilibrium water table level has been achieved, and that during average or wetter than average conditions, drainage is sufficiently rapid to remove excess water. It is not yet clear whether this represents the long term equilibrium position.

Further reference to figures 21 and 22 indicates that only prolonged periods of drainage and/or evaporation lowered the water table below the equilibrium level, and that recovery occurred upon return to the average rainfall conditions. The water table in the 5 m drainage field exhibited a general upward trend during the months of June and July, indicating the equilibrium level is at a depth not greater than 60 cm.

Figures 28 and 29 shows the water table changes at the Markland site one year after drainage. If we compare the water table data for Markland 1988 and St. Shotts 1988 we see that the levels in all fields are similar even though the Markland site has only one year of drainage as opposed to two years for the St. Shotts site. This can be explained by the fact that there is a larger layer of undecomposed peat at the Markland site, thus the larger initial drainage. It is believed that the St. Shotts site reached similar levels in the first year (1987) due in part to the extremely dry conditions that year.

4.3.3 Peatland Drainage Models for St. Shotts

The following peatland drainage models are presented to show the possible long term drainage trends that can be expected at the St. Shotts site.

Ivanov (1975) presents a model of bog development which can be adapted to this peatland drainage site. Consider two adjacent ditches at height (h) above a mineral substrate, and the intervening mass of peat with hydraulic conductivity (K). For a given average annual vertical water flux (w), there is an equilibrium water table elevation (y) above the mineral substrate at a distance (x) from the ditch, given the distance (α) from the ditch to the centre of the field:

$$y = [w/K\ (2\alpha x - x^2) + h^2]^{1/2}$$

The average vertical flux (w) can be represented by the depth of average annual runoff (which for the nearby St Shotts River and North West Brook is 1850 mm/y). This accounts for precipitation, less evaporation and seepage losses. Hydraulic conductivity determined by pumping tests averaged 0.031, 0.048, and 0.030 m/d for 5, 10, and 20 m drainage fields respectively. The results are shown in Figure 30a, 30b and 30c (predicted equilibrium water table (curved line) at a 5, 10, and 20 m drainage site, based on Ivanov's (1975) model. The lower axis represents the contact between mineral soil and peat, and the horizontal line is the actual peat surface. Only the 5 m site has a predicted equilibrium water table which is all below the surface), where the curved water table profile is plotted relative to the substrate (bottom axis), and the actual peat surface is plotted (horizontal line). The model is unrealistic in that it assumes a continuous vertical water flux at the average rate, rather than periodic bursts of activity. Furthermore, it does not account for continued drainage in the winter while precipitation is stored as snow, and that snowmelt runoff may not cause recharge when the peat is frozen (Price and Fitz-Gibbon 1987). However, with that proviso, the model indicates that the 5 m drainage fields have a long term equilibrium water table well below the surface, while 10 and 20 m fields do not.

A second model (Walker 1952, cited from Boelter 1972) predicts the water table recession (dy) over time (t), as:

$$\frac{dy}{dt} = \frac{2Kt \cos\theta}{Py}$$

where θ is the angle between a vertical and a straight line between the water table in the ditch and the water table midway between the ditches, p is the non-capillary porosity of the soil and the other terms are as previously defined. Assuming the water table is at the bottom of the ditch, and an initial water table at centre field of 20 cm below the surface, the water table recession for 20, 10, and 5 m sites is 0.46, 1.53, and 1.7 cm/d. Compare this to the average daily flux of 0.51 cm/d (1850 mm/y), and it is evident that both the 10 and 5 metre fields will experience a long term decline in their water tables, whereas the 20 m field will not.

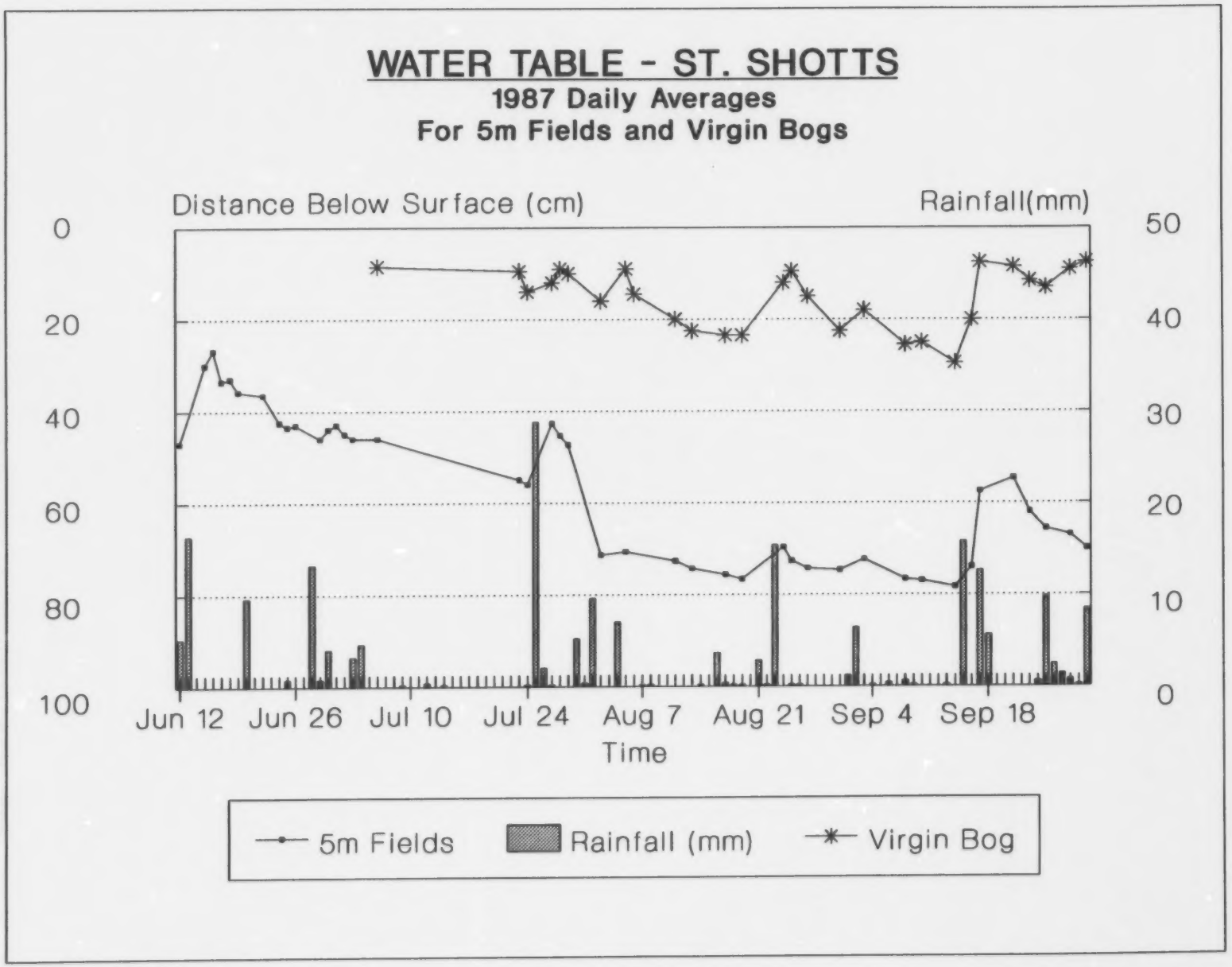


Figure 21(a) Daily water table levels on a 5 meter field (St. Shotts, 1987)

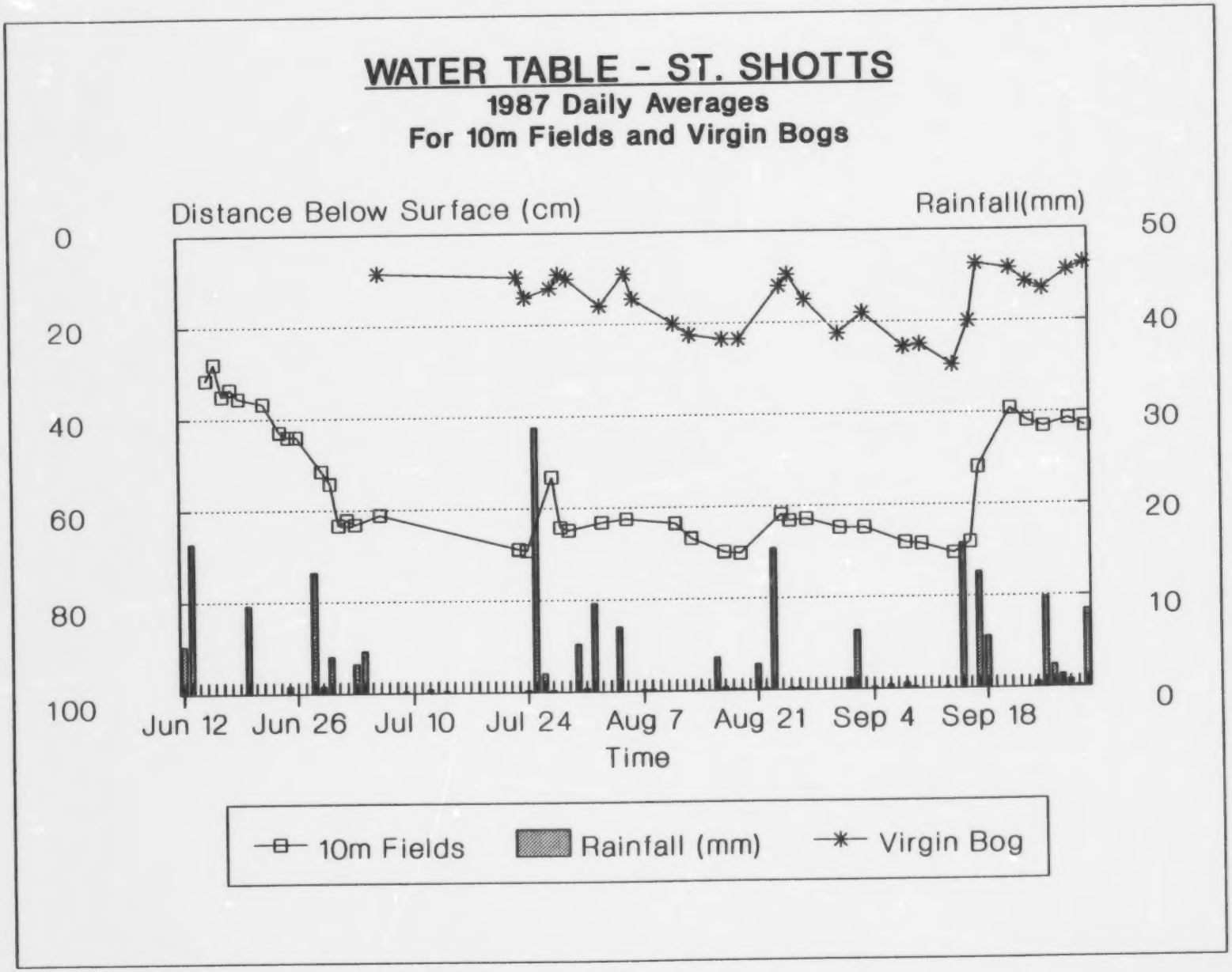


Figure 21(b) Daily water table levels on a 10 meter field (St. Shotts, 1987)

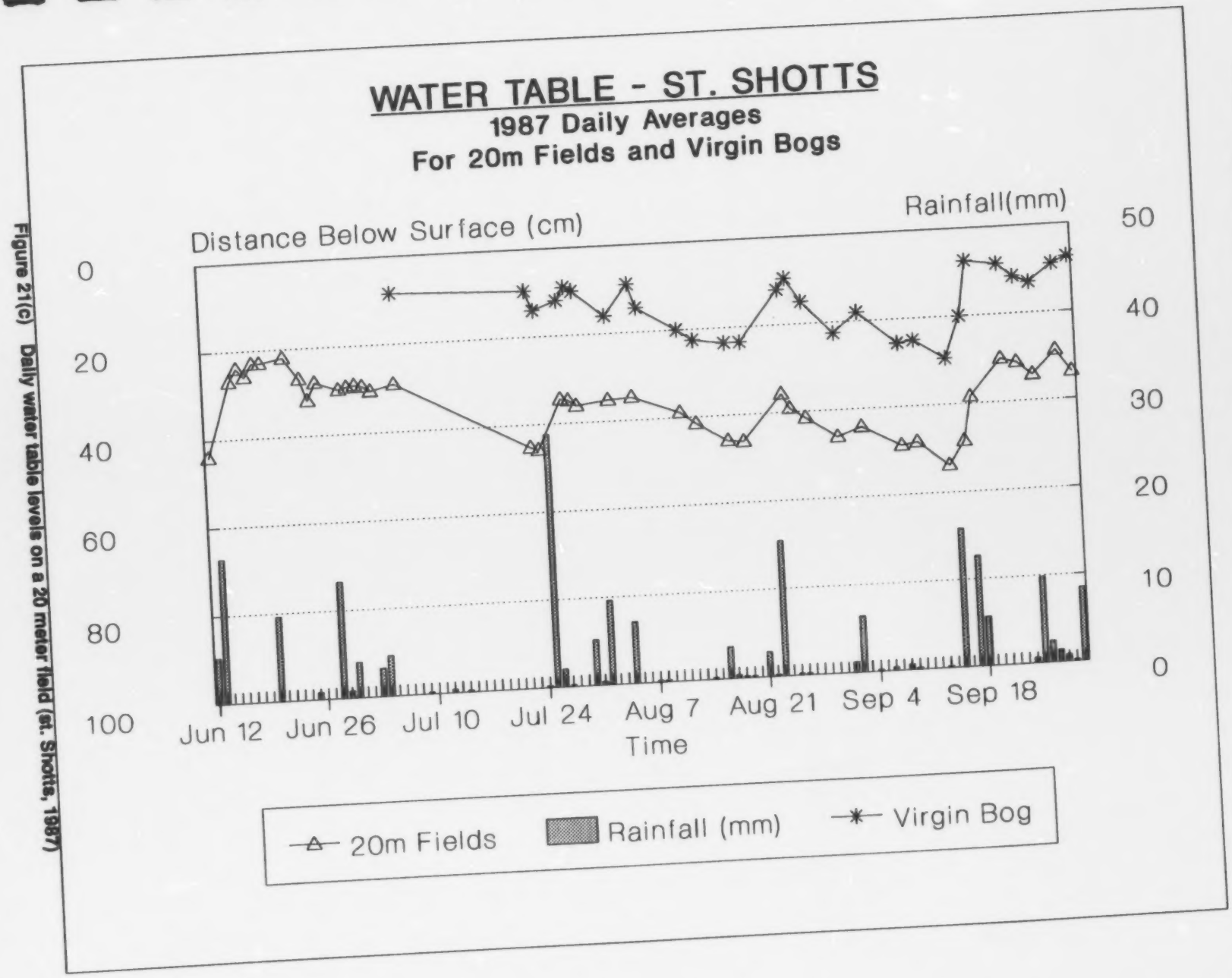


Figure 21(c) Daily water table levels on a 20 meter field (St. Shotts, 1987)

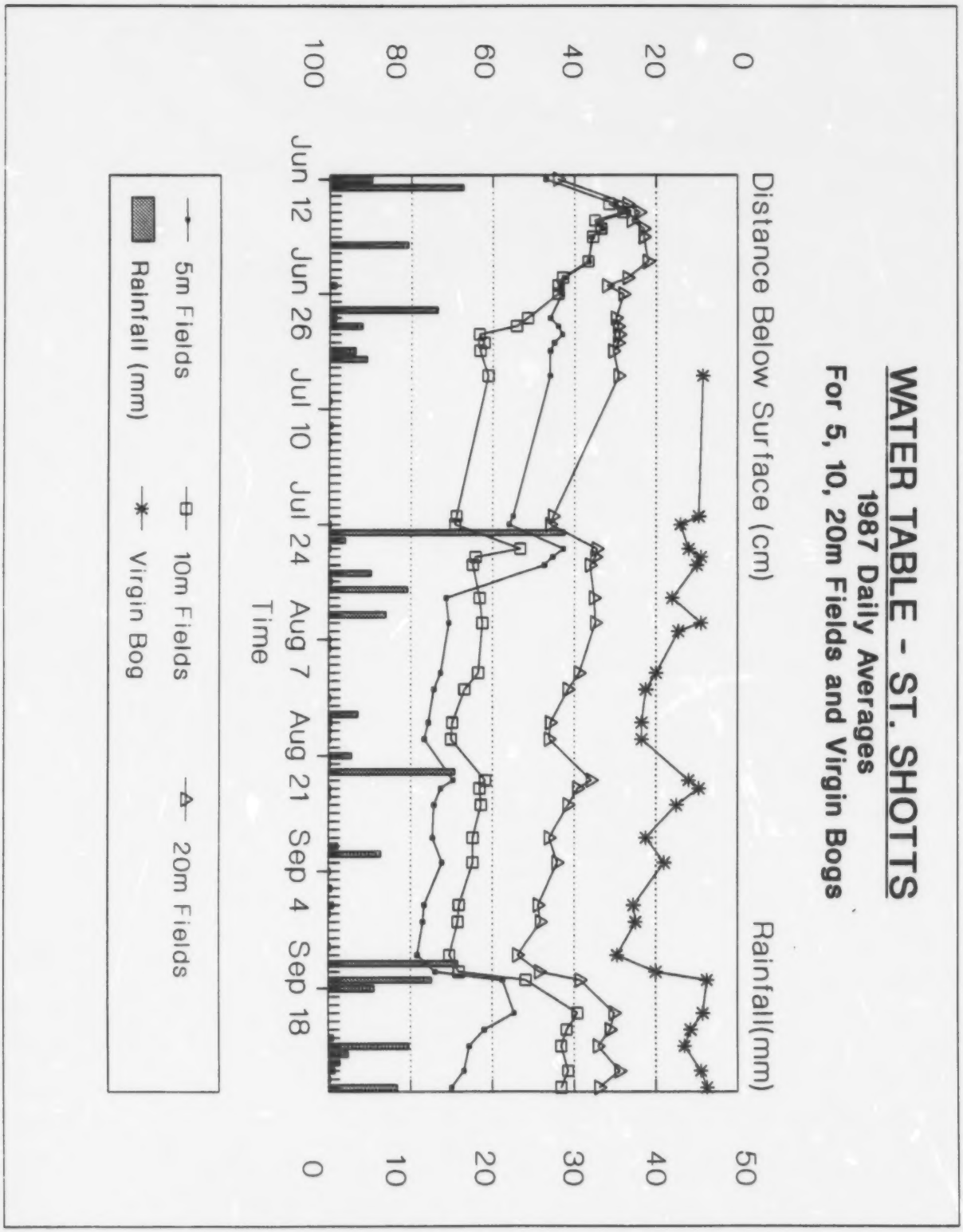


Figure 22 Daily water table levels on all fields (St. Shotts, 1987)

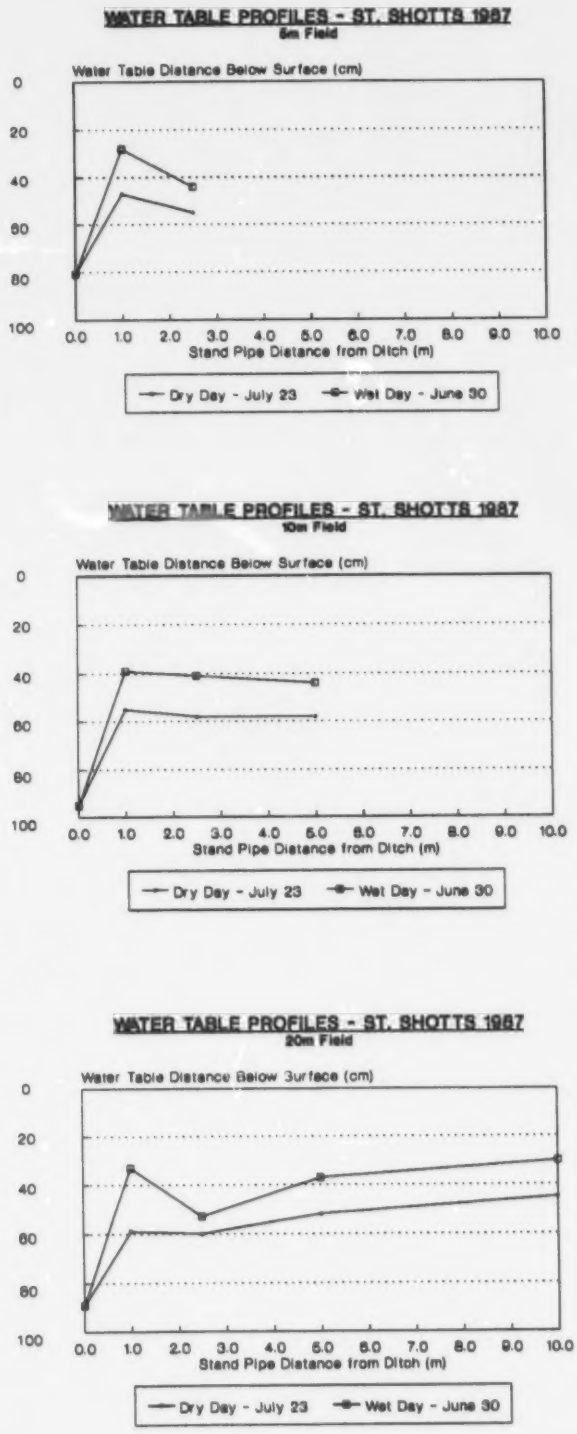
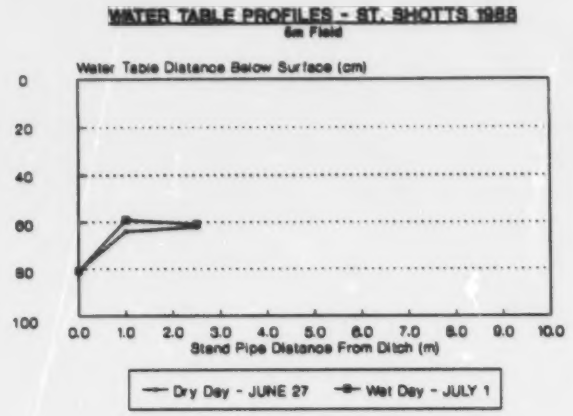
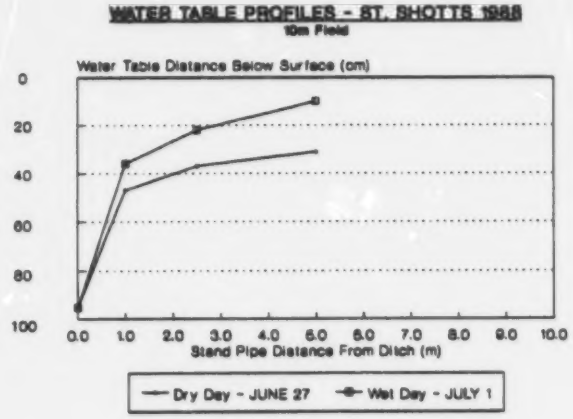


Figure 23 Lateral water table profile for a 5, 10, and 20 m field on a wet and dry day (St. Shotts, 1987)





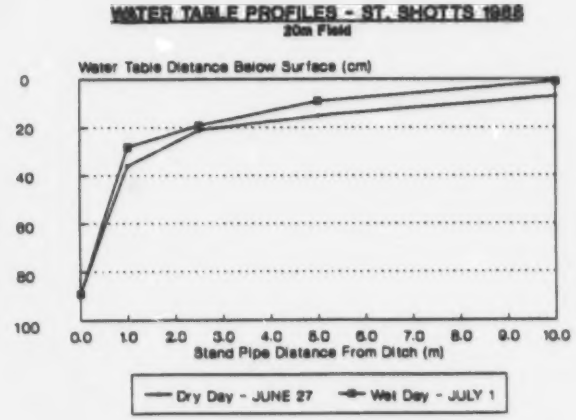


Figure 24 Lateral water profile table for a 5, 10, and 20 m field on a wet and dry day (St. Shotts, 1988)

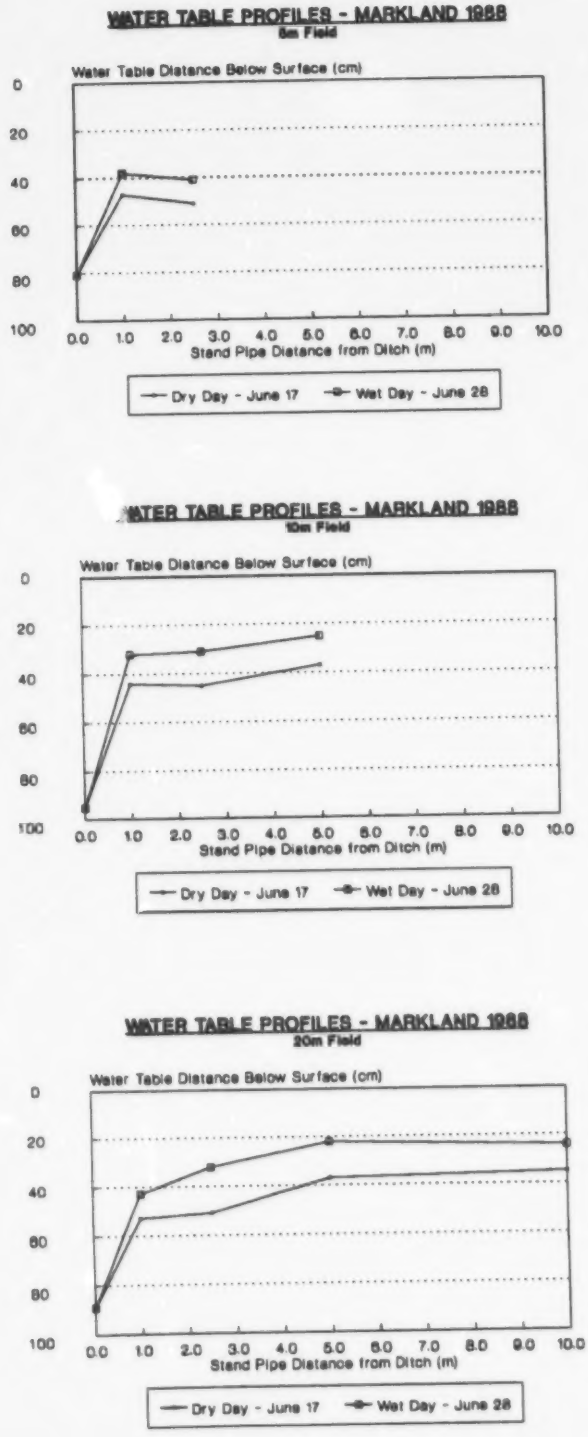


Figure 25 Lateral water table profile on a wet and dry day (Markland, 1988)

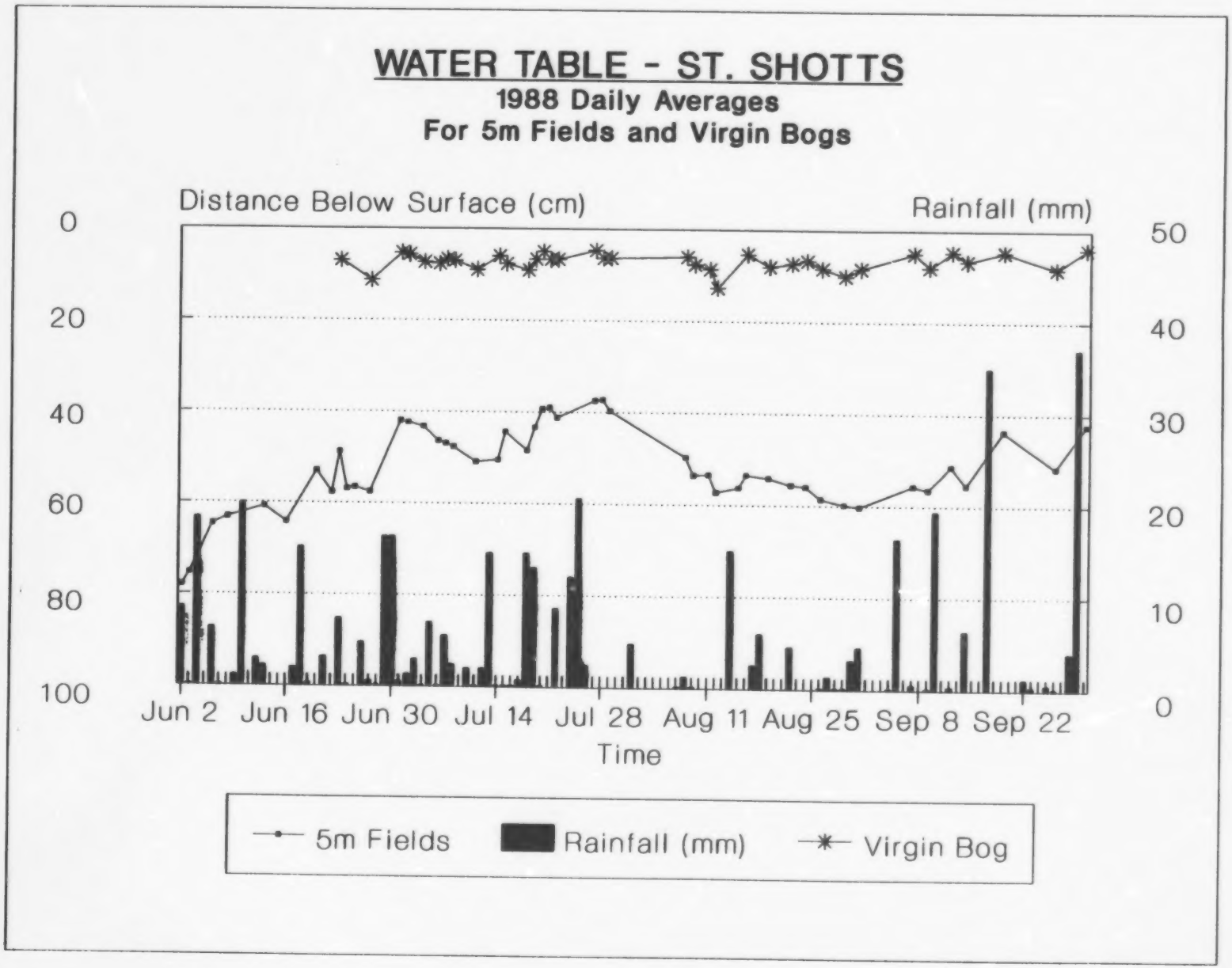


Figure 26(a) Daily water table levels on a 5 meter field (St. Shotts, 1988)

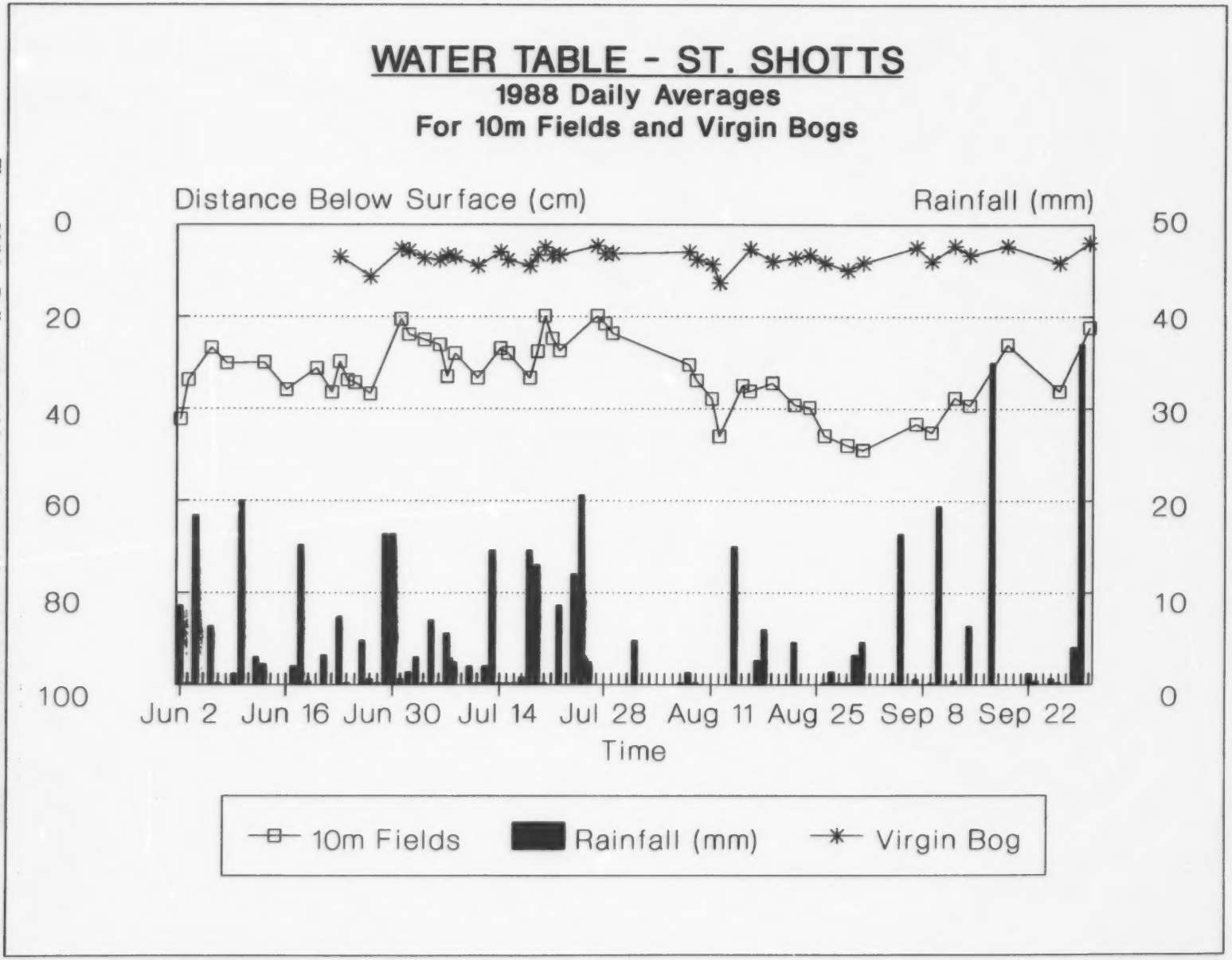


Figure 26(b) Daily water table levels on a 10 meter field (St. Shotts, 1988)

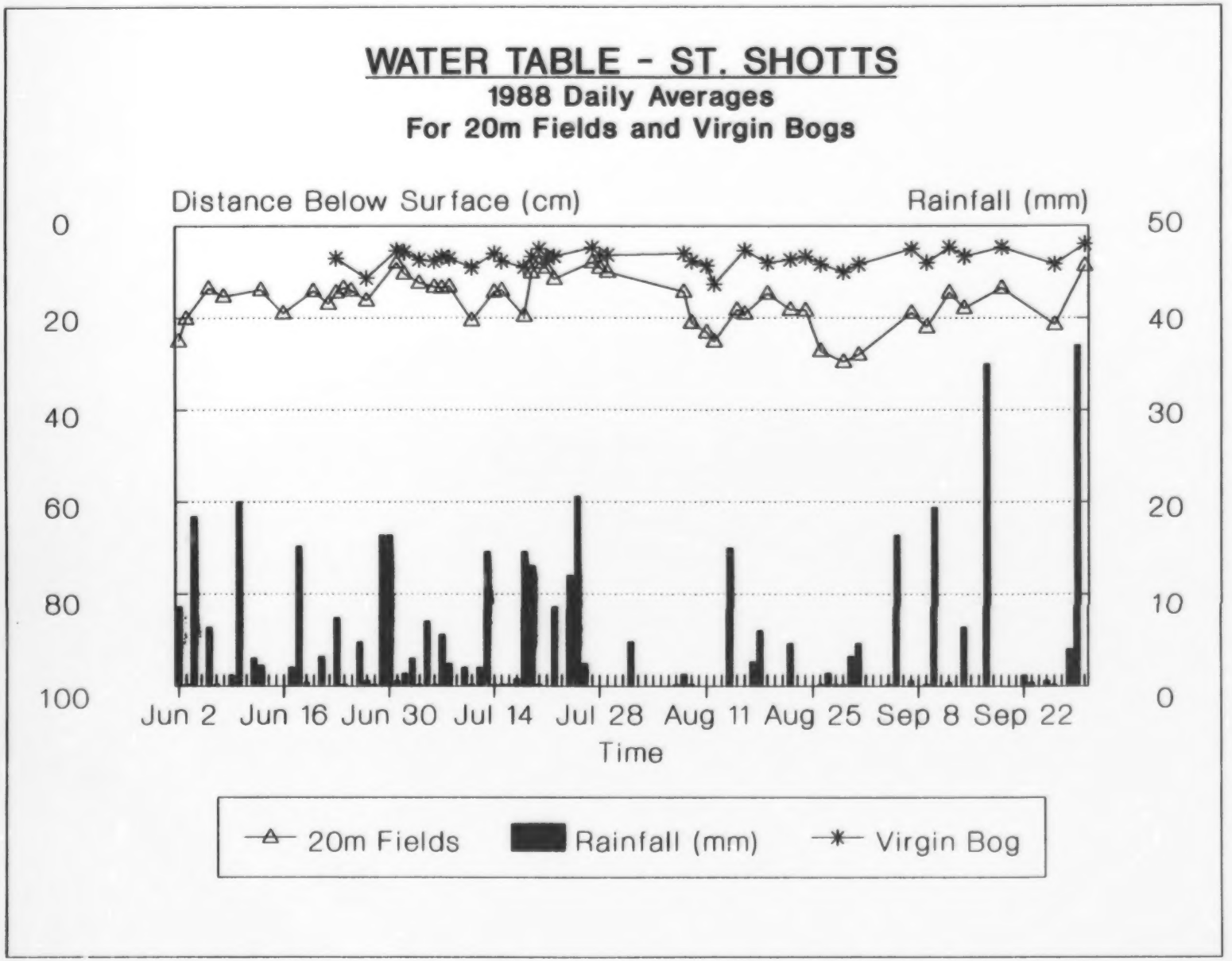


Figure 26(c) Daily water table level on a 20 meter field (St. Shotts, 1988)

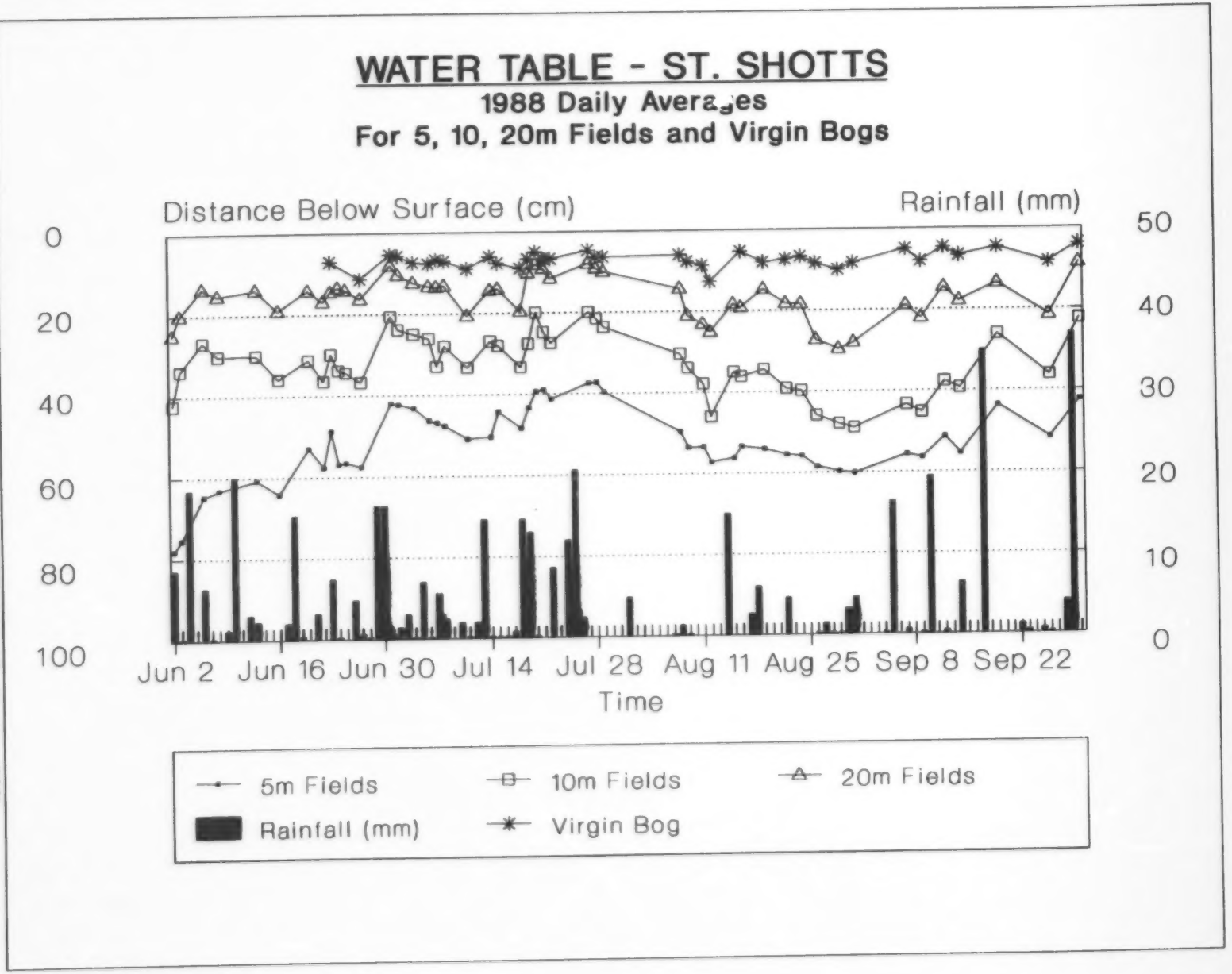


Figure 27 Daily water table levels on all fields (St. Shotts, 1988)

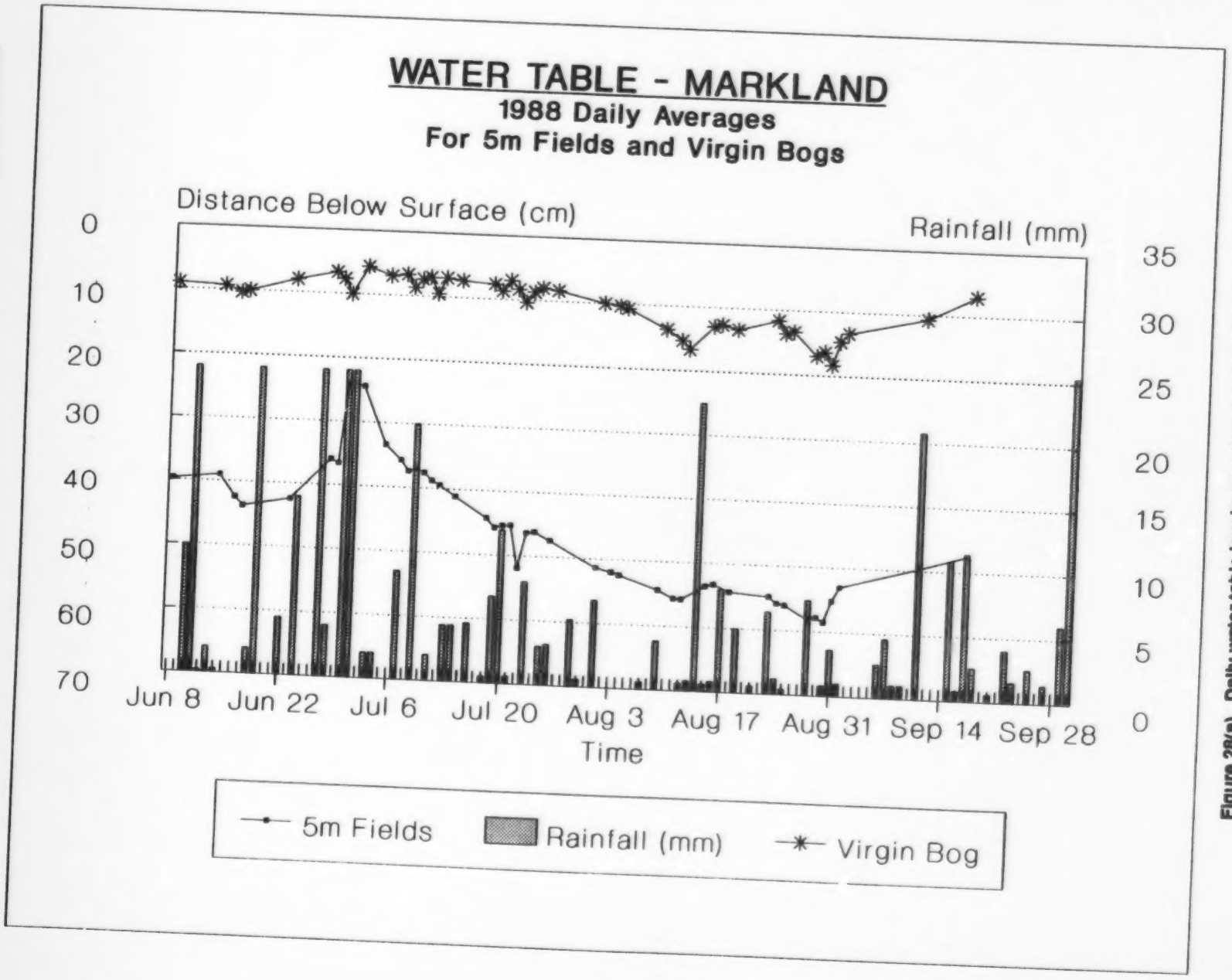


Figure 28(a) Daily water table levels on a 5 meter field (Markland, 1988)

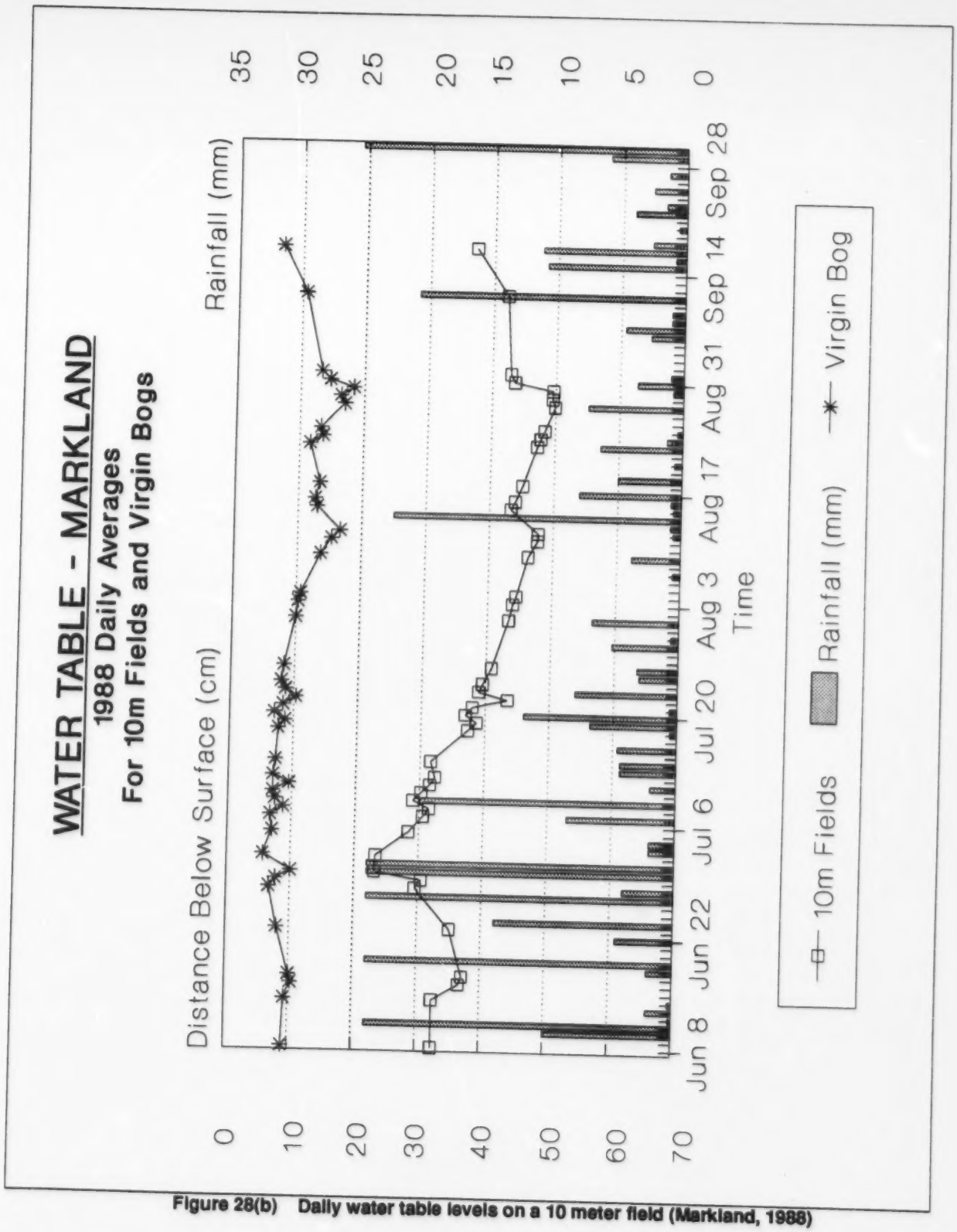


Figure 28(b) Daily water table levels on a 10 meter field (Markland, 1988)

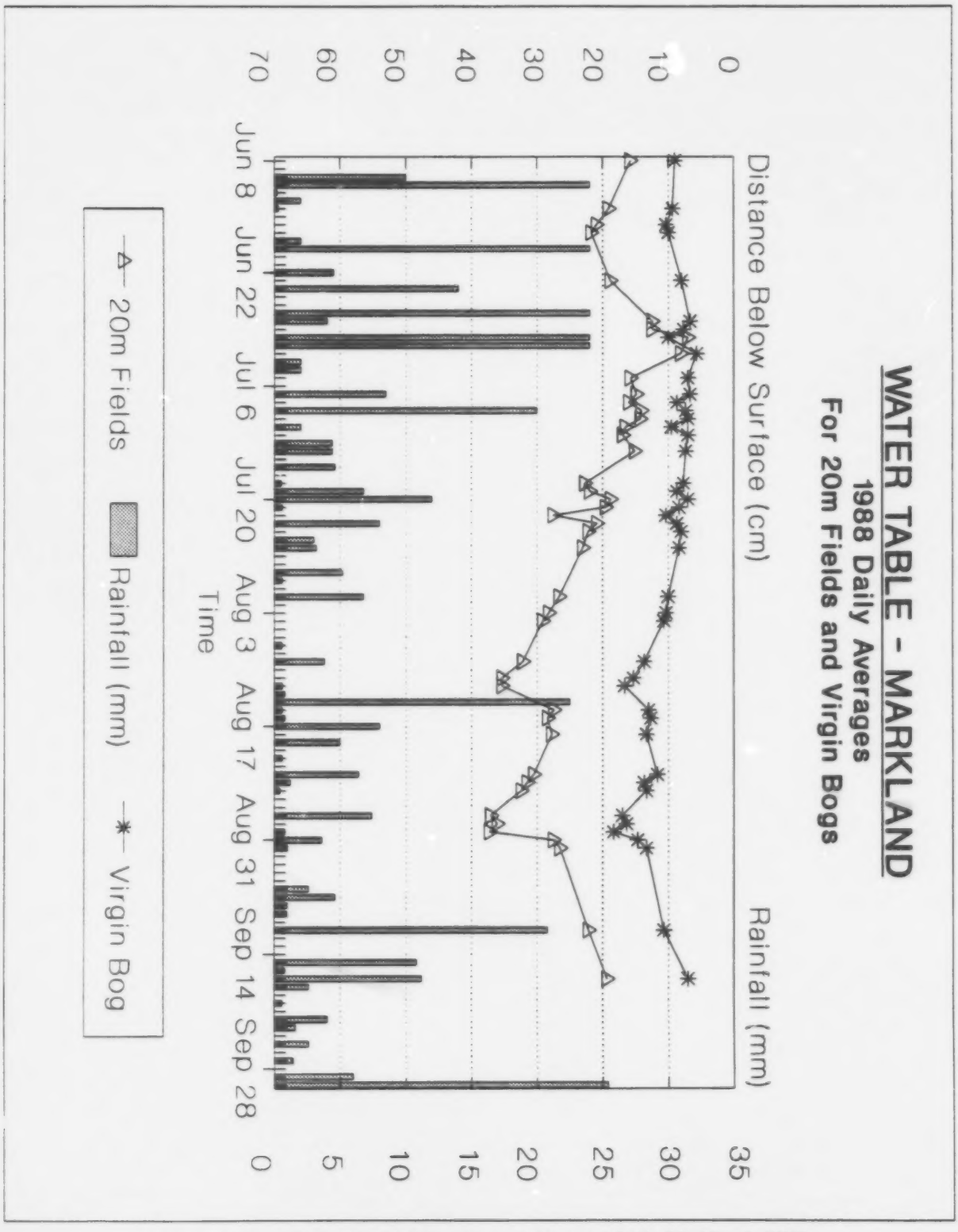


Figure 28(c) Daily water table levels on a 20 meter field (Markland, 1988)

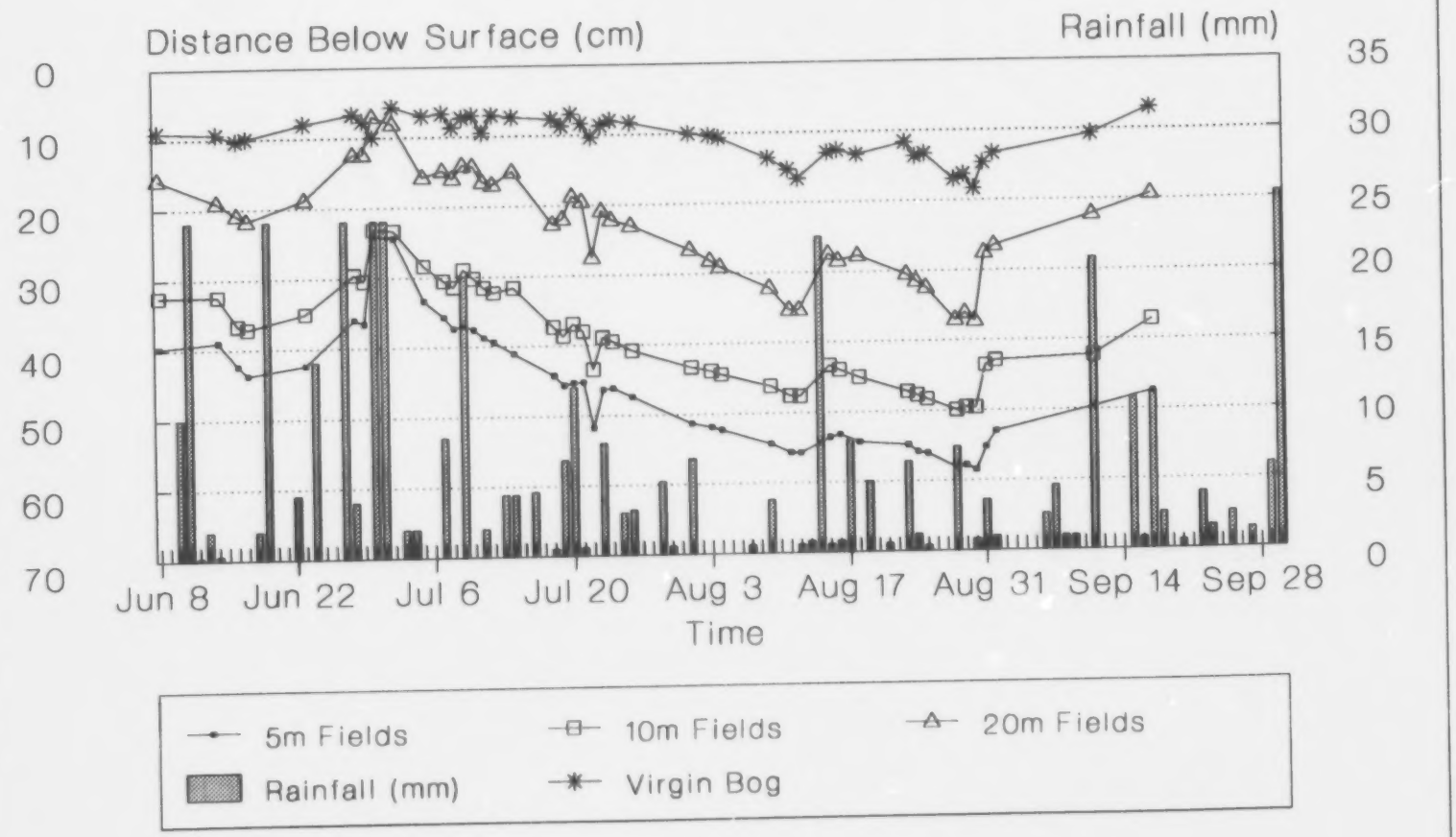


Figure 29 Daily water table levels on all fields (Markland, 1988)

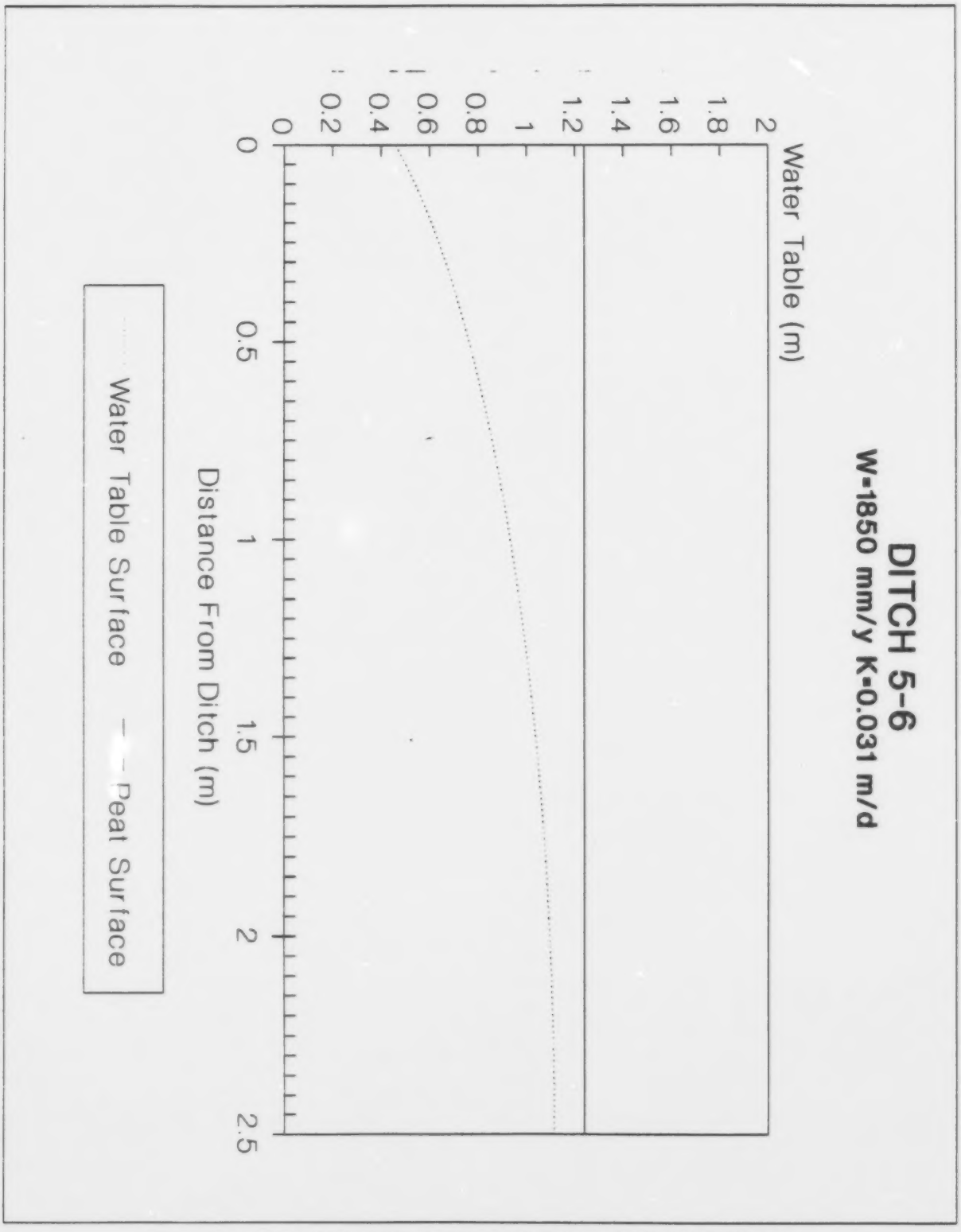


Figure 30a Predicted equilibrium water table for a 5 m field (St. Shotts)

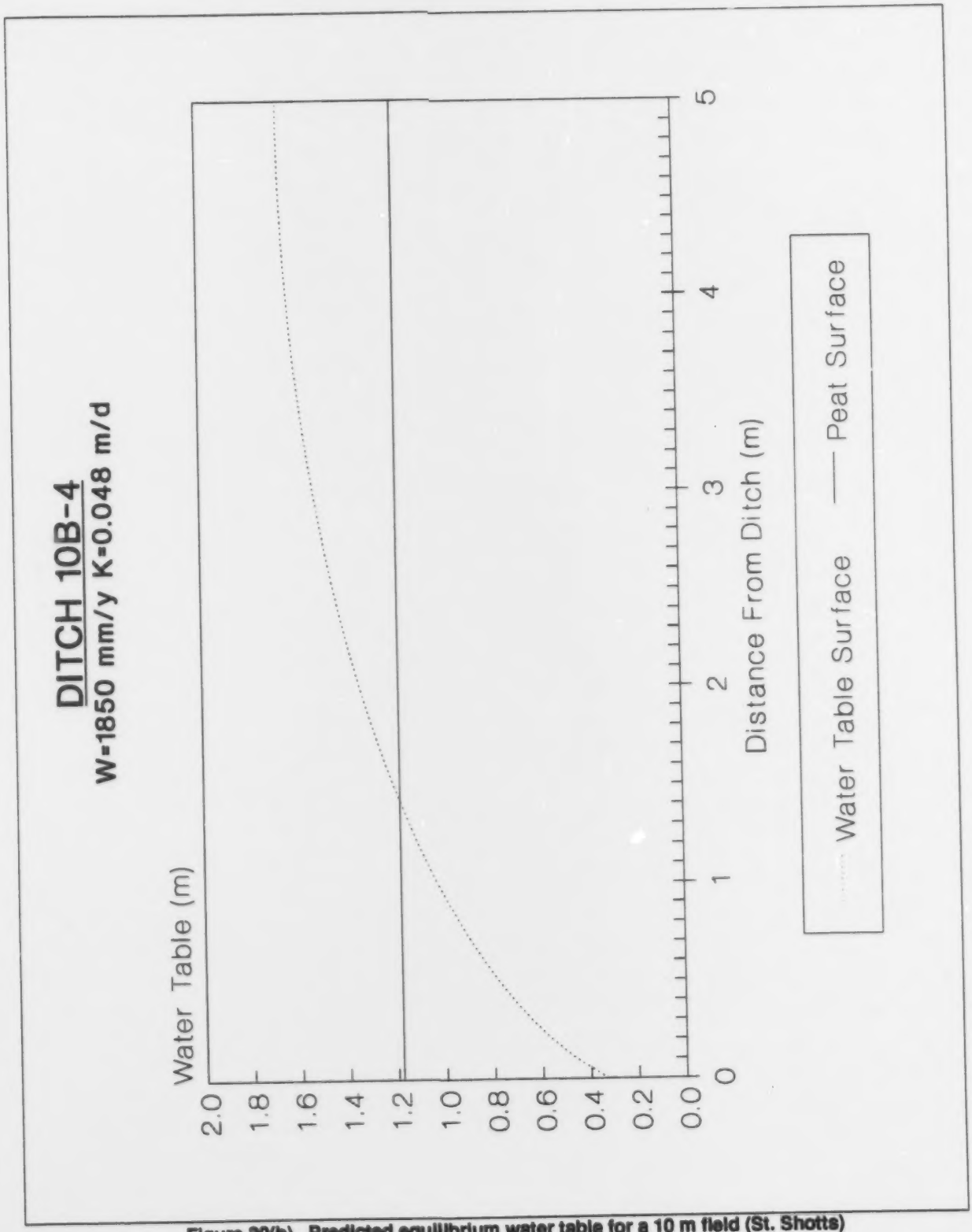


Figure 30(b) Predicted equilibrium water table for a 10 m field (St. Shotts)

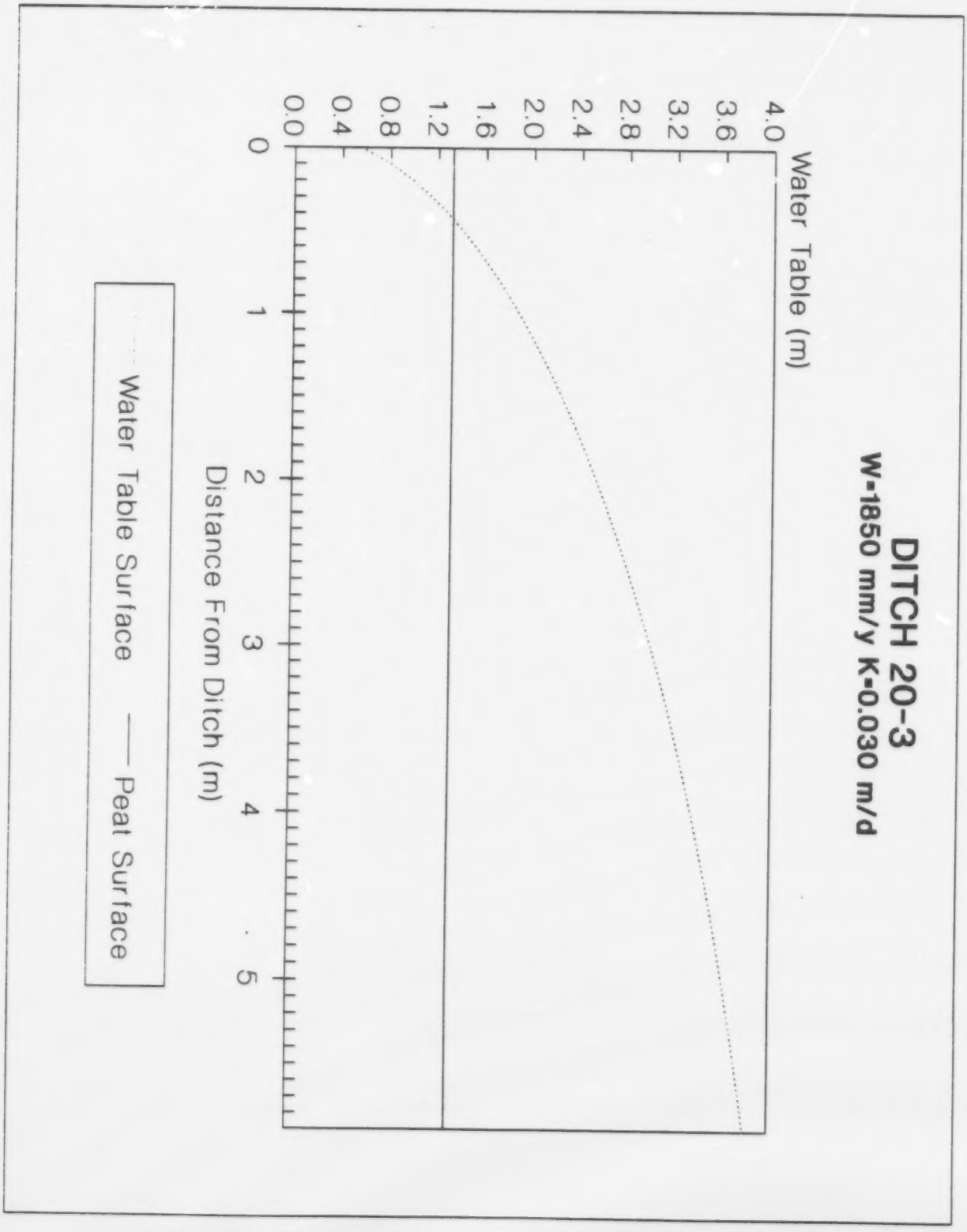


Figure 30(c) Predicted equilibrium water table for a 20 m field (St. Shotts)

The latter of the two models produce the most realistic results, although they are similar in many respects. The field data seem to correspond to the results of the latter model. Both the 10, and 5 m fields have shown significant drainage.

4.3.4 Conclusions

The nature of the two layer soil system on peatlands has resulted in a very rapid initial drainage of the upper layer. A very dry summer in 1987 accelerated the draining, and may have caused subsidence and compression. Drainage appears to be occurring appreciably in the 5 and 10 m fields, although a quasi-equilibrium state may already have been reached. The water table and the soil moisture content have both shown a partial recovery from that dry year. Further observations are required to determine if the water table has reached an equilibrium level already, and if the moisture content will continue to decline.

5.0 ECONOMIC EFFECTS OF VARIOUS DRAINAGE PATTERNS ON PEATLAND DEVELOPMENT

The normal development of peatlands for the production of horticultural or fuel products requires that the peat be sufficiently drained to allow the operation of heavy equipment. The accepted drainage schemes involve the use of three types of ditches; a perimeter ditch, a collector ditch and a field ditch. The perimeter ditch is used to isolate the developed area from the remaining peatland, thereby reducing the in-flow of sub-surface water. The collector ditch is used to channel water from the field ditch into the perimeter ditch. The collector ditch is not always necessary depending upon the configuration of the bog or peatland development. The field ditch is used to provide sufficient free flowing channels for the water in the peat to drain into.

Peatland development for fuel production has been carried out for many years in Europe, Scandinavia and the USSR. "In Europe the customary ditch spacing is 10 - 20 meters. A 10 meter spacing, in most cases, provides an unnecessary dense ditch pattern. Only in areas with high precipitation, very highly humified peat, and very flat topography can it be justified. The close ditch spacing adds to the preparation and maintenance costs, increases the loss of useable peat area and can create problems with the operation of heavy equipment" (Extracted from *Peat in Ontario* by Monenco Ltd. Montreal, page 47).

The conditions encountered in Newfoundland are quite often those which require exceptional drainage techniques. The purpose of the R&D efforts being carried out at Markland and St. Shotts are to determine those factors which affect drainage and to analyze their impact on the rate of drainage in order to optimize drainage techniques.

The rate of drainage directly affects the time required to drain a bog to a sufficient level for harvesting operations to begin. This time varies depending upon peat type, peat depth, precipitation, length of frost free season and the drainage pattern chosen, to name a few. In order to analyze the economic effects of the drainage patterns it is necessary to look at the drainage time required and the associated cost incurred over this period.

For the purposes of this analysis it is assumed that in order to economically develop a sod peat operation a minimum annual production of 10,000 tonnes will be required. Depending upon whether a single or multiple harvest is possible, the area required for production will vary dramatically. In the southern coastal areas of Newfoundland, the prospects for multiple harvests are somewhat doubtful. Therefore, this analysis will concentrate on the requirements resulting from a single harvest scenario. It is estimated that 200 hectares of productive area will be required to produce the 10,000 tonnes annually. The variations in gross area required for a 200 hectare production site are given in the following tables.

Table 2: Variation in Gross Area Requirements for a 200 Hectare Production Site

Ditch Pattern (meters)	% Loss of Productive Area	Gross Area Required for a 200 Hectare Development
20	5%	210
10	10%	220
5	20%	240

As the ditching intensity increases the total length of perimeter and field ditching also increases. Tables 3 and 4 give the estimated requirements for both types of ditch.

Table 3: Estimated Perimeter Ditching Requirements for a 200 Hectare Production Site

Drainage Pattern (m)	No. ha Required for 200 ha prod. area[1]	No. Meters[2]	Total No. meters	Cost/Meter ($)	Total Cost ($)
20	210	125	26,250	3.12	81,900
10	220	125	27,500	3.12	85,800
5	240	125	30,000	3.12	93,600

1. Calculated based upon the amount of area lost to ditching.
2. Based upon 30 ha production area.

Table 4: Estimated Field Ditching Requirements for a 200 ha Production Site

Drainage Pattern (m)	No. ha Required for 200 ha prod. area	No. Meters (ha)	Total No. Meters	Cost/Meter[1] ($)	Total Cost ($)
20	210	250	105,000	0.72	75,600
10	220	1,000	220,000	0.65	143,000
5	240	2,000	480,000	0.58	278,400

1. This assumes a 10% and 20% reduction in the 10 and 5 metre spacings due to the large amount of ditching required i.e. greater productivity.

The requirement for increased gross area as the ditching intensity goes up results in additional costs associated with initial surveying and layout in peatland development. Table 5 gives the estimated costs for this component of a development.

Table 5: Estimated Costs for Initial Surveying and Layout

Drainage Pattern (m)	No. ha Required	Cost/ha[1] ($)	Total Cost ($)
20	210	15	3,150
10	220	15	3,300
5	240	15	3,600

As with ditching, the increased intensity results in a requirement for greater maintenance. The costs associated with the maintenance and cleaning of ditches are given in Table 6.

Table 6: Estimated Field Maintenance and Cleaning Costs

Drainage Pattern (m)	No. ha required	Cost/ha[1] ($)	Total Cost ($)
20	210	15	21,000
10	220	150	33,000
5	240	200	48,000

1. Based upon $0.20/m, $0.15/m and $0.10/m for the 20, 10 and 5 metre spacings respectively.

5.1 Analysis

The analysis of the prospective benefits of more intensive drainage techniques on peatlands in Newfoundland is based upon comparisons between the total cost of the drainage phase for a 20 meter drainage pattern and the costs associated with 10 and 5 meter patterns. In the case of the 20 meter pattern a 7 year drainage period is assumed. It is recognized that the 7 year period is the upper range of the drainage required for the 20 meter pattern and as such it represents an optimistic viewpoint. However, it has not been proven to date that the 20 meter pattern is effective in draining peatlands in the southern coastal areas of Newfoundland.

The following component activities were used in the determination of the total cost incurred during the drainage phase.

- Initial surveying and layout of the development
- Perimeter ditching
- Field ditching
- Field maintenance

For the purposes of this analysis it has been assumed that the development costs are debt financed and as a result interest costs have been included in the totals. The annual cost of maintenance has been escalated in order to account for increased operating and labour costs. The entire analysis is based on current dollars.

Based upon knowledge of the peat resources of Newfoundland and in particular, the fuel peat resources on the Avalon and Burin peninsulas, it is assumed that in order to develop sufficient area to annually harvest 10,000 tonnes of peat, a minimum of three sections will be required. This assumption primarily impacts on the amount of perimeter ditching and to a much lesser extent on the amount of field ditching. The base case parameters that are used in the analysis are located on the following page.

The type of analysis used is based upon a comparison of the 20 meter base case with the 5 and 10 meter drainage systems. In this way the relative economic benefits of a shorter developmental phase for fuel peat projects are determined. The comparisons made are limited to a full calender year and assume that "normal" climatic conditions occur. Determination of the time required for the proposed development to become operational is carried out for the three schemes i.e. 5, 10, and 20 meter fields.

In other words "how much faster must the 5 and 10 meter systems drain to be equivalent to the 20 meter system based on a 7 year drainage period".

Base Case 20-meter Ditch Spacing

Annual production	10,000 tonnes (50% M. C.)
Yield per hectare	50 tonnes/ha/yr
No. hectares	210 ha (see Table 1)
No. sections	3
Field ditch spacing	20 meters
Minimum depth of peat deposit	1.5 m
Range of depth of peat deposit	1.5 - 2.5 m
Interest rate	10.0%
Drainage time required before start up	5-7 years
Perimeter ditching	26,250 m @ 125 m/ha
Field ditching	105,000 m @ 500 m/ha

5.1.1 Results of the Analysis

The results of the analysis of the costs associated with intensive peatland drainage show that the drainage phase of a 200 hectare (productive area) development utilizing a 20 - meter drainage pattern will result in a total expenditure of $543,395 over a 7 year period. In order for the 10 and 5 meter drainage patterns to result in an equivalent expenditure drainage would have to occur in 4.39 and 1.82 years respectively.

A sensitivity analysis was carried out on the base case scenario. This analysis was constructed by varying each of the cost components 40% higher and 40% lower (in increments of 10%) than the base case. The resultant change in the time required for drainage to occur to maintain an equivalent total expenditure to the 20 meter pattern was calculated. The results are plotted in figures 31 through 36. Each of the factors affecting the total expenditure are discussed as follows.

5.1.2 Interest Rate

The results indicate that both the 5 and 10 meter drainage patterns are sensitive to fluctuating interest rates. Lower interest rates and a shorter drainage period must occur for the 5 and 10 meter to be equivalent to the 20 meter. Logically this sensitivity indicates that when the cost of money is high an intensive drainage pattern is favoured. The 5 meter pattern showed greater sensitivity than the 10 meter with ranges of 1.46 and 0.85 years respectively.

5.1.3 Escalation Rate

Both drainage patterns showed little sensitivity to escalation rates which is due to the fact that escalation is only applied to the annual maintenance costs. These costs are small in comparison to the initial development costs.

5.1.4 Perimeter Ditch Costs

Perimeter ditching costs did not show much sensitivity in either the 5 or 10 meter drainage patterns. Only minor variations in the total cost occurred as a result of fluctuations in perimeter ditching costs. This is consistent with the assumptions made for perimeter ditching requirements (see Table 3).

5.1.5 Field Ditching Costs

This factor activity exhibited the most sensitivity in both the 5 and 10 meter drainage patterns. The range of drainage time required was 1.41 and 0.61 years in the 5 and 10 meter patterns respectively. This variable was the only one to show an increasing drainage period with a decreasing cost of the field ditches. The cost of field ditches is by far the single most important contributor to drainage costs. If intensive drainage patterns such as 5 or 10 meter spacings must be utilized, then careful attention has to be paid to techniques that can give the lowest possible cost per meter. Existing drainage techniques are likely to be too costly to produce significant gains in the 5 meter spacing and only modest gains in the 10 meter spacing when compared with the 20 meter spacing.

Fig. 31

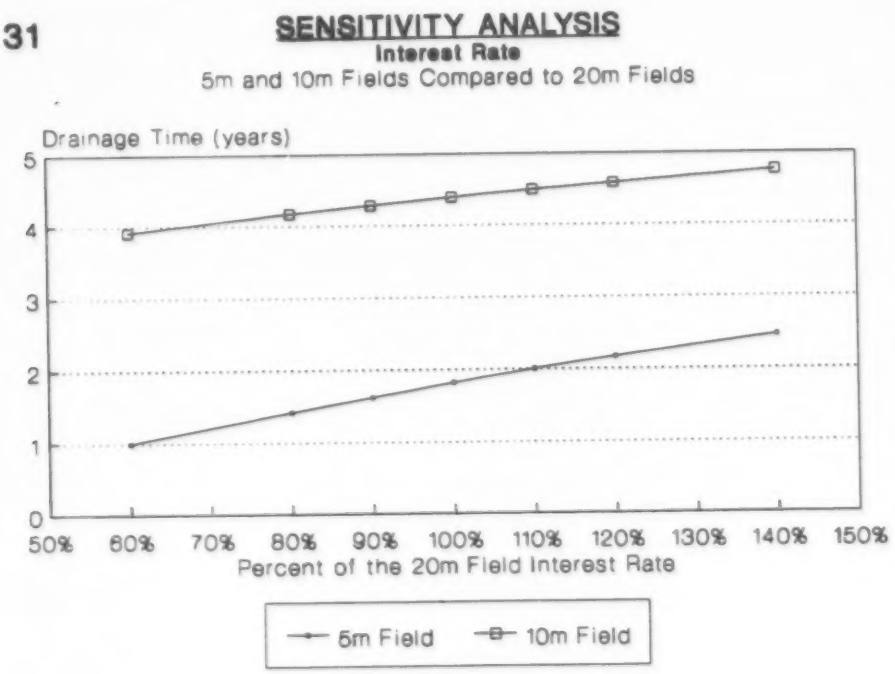


Fig. 32

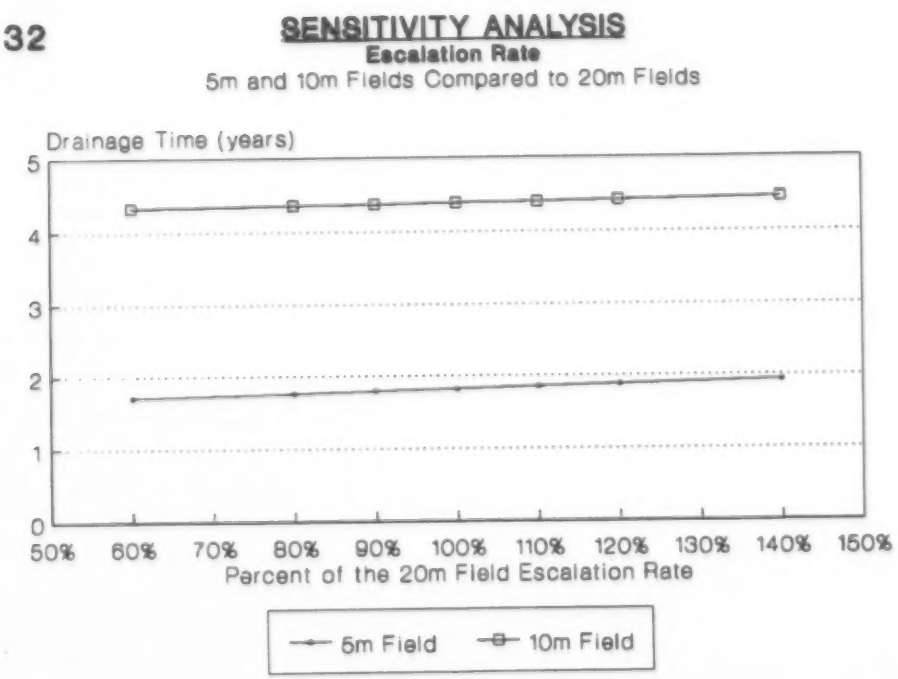


Figure 31 Sensitivity analyses interest rate

Figure 32 Sensitivity analyses escalation rate

Fig. 33

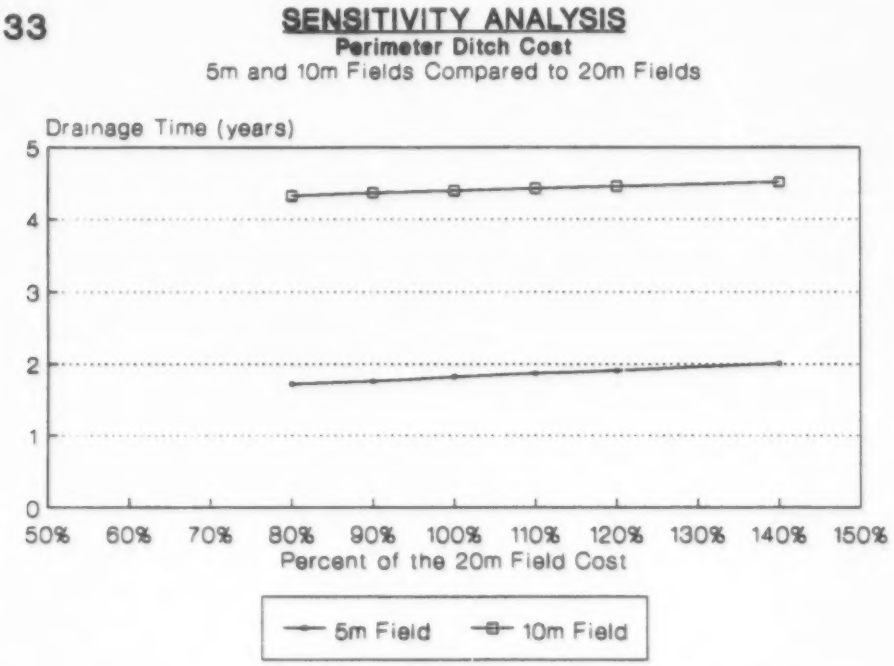


Fig. 34

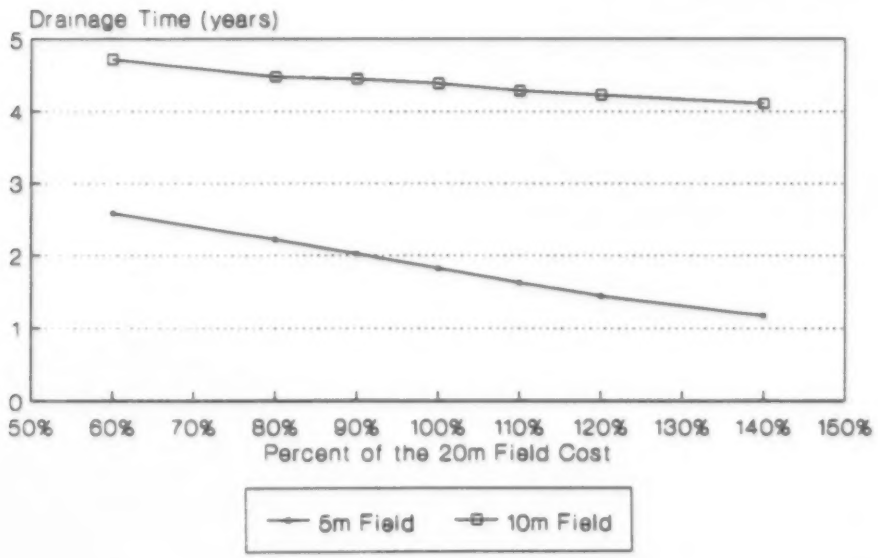


Figure 33 Sensitivity analyses perimeter ditch cost

Figure 34 Sensitivity analyses surveying and layout

Fig. 35

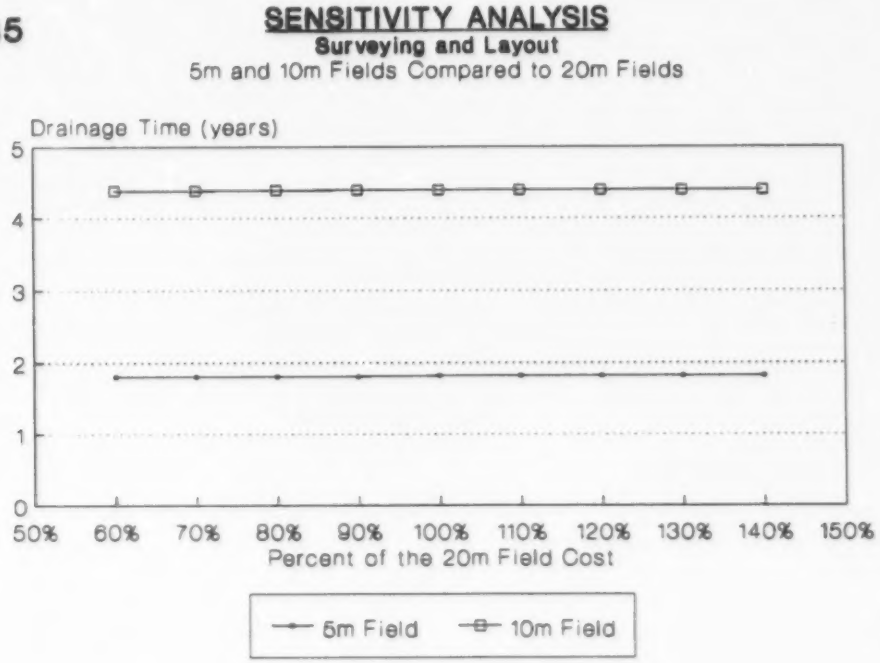


Fig. 36

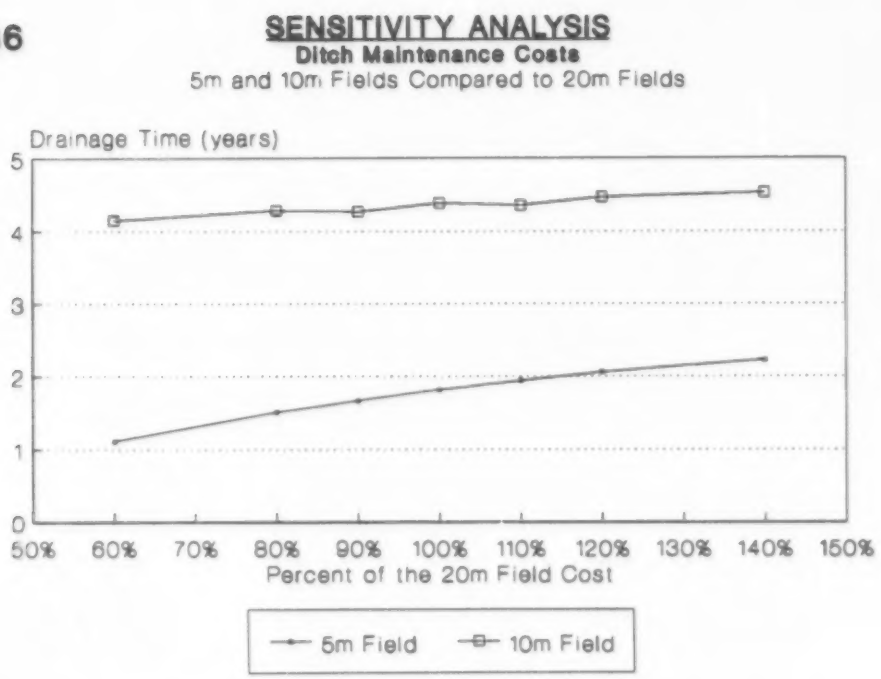


Figure 35 Sensitivity analyses surveying and layout

Figure 36 Sensitivity analyses ditch maintenance costs

5.1.6 Initial Surveying and Layout

The initial cost associated with the surveying and layout of peatland developments was found to have a negligible effect on total development costs.

5.1.7 Field Maintenance

Field maintenance costs were found to have a significant impact on total development costs, particularly in the 5 meter case. This is directly related to the fact that intensive drainage requires more ditch maintenance due to the greater amount of ditching.

5.2 Conclusions

Intensive drainage methods, such as those under evaluation at St. Shotts and Markland, are likely to result in shortened drainage periods being required prior to the operational phase of peatland development. Unless the drainage period can be reduced sufficiently such that the total expenditure during the drainage period is less than the expenditure associated with standard 20 meter ditch spacing, then it is not feasible to go beyond the standard. Preliminary results indicate that, with a 5 meter spacing the water levels in the field would have to be at a level whereby the moisture content in the surface layer (30 cm) would be 80-81% after 3 years, and with 10 meter spacing in lessthan 5 years. Interest rates, ditching and maintenance costs have a significant impact on the drainage period and thus, must be carefully considered before intensive drainage methods are employed. The cost associated with field ditches is particular by sensitive to the drainage period. Efforts should be expended on establishing lower cost methods of installing and maintaining these ditches.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Conventional peat development techniques demand that the first requirement is a well drained field with a firm, even drying surface to provide stability and increase the trafficability of the deposit. To date peat developments on the blanket bogs of the southern Avalon peninsula have not been able to achieve these goals. This study was designed to provide a database to help predict the drainage patterns that might be necessary to proceed with successful peat development. The major conclusions of this study are as follows:

- St. Shotts and Markland exhibit much higher precipitation levels over the summer months than peat production areas of Ireland or Finland. This serves to lengthen the period necessary for local peatland drainage and for sod drying. The persistence of fog also contributes to hamper the drainage and drying of peat; this is significant at coastal St. Shotts but not at Markland.

- It was found that peat sods extruded on a dry surface dried much faster than those extruded on the wet fields even under the same climatic conditions. This indicates that the drying surface plays a most important role in the drying of peat sods. In order to dry sod peats on the fields, the fields must be properly drained. No relationship was found between drying rate and average wind speed. This is not unexpected since periods of relatively higher mean wind speed were associated with incidents of high and low rainfall levels alternately. This implies that wind speed must be combined with a specific influence (e.g. higher air temperature, decreased humidity) to effect an increase in drying rate.

- The nature of the two layer soil system on peatlands has resulted in a very rapid initial drainage of the upper layer. A very dry summer in 1987 accelerated the draining, and may have caused subsidence and compression. Drainage appears to be occurring appreciably in the 5 and 10 m fields, although a quasi-equilibrium state may already have been reached. The water table and the soil moisture content have both shown a partial recovery from the initial dry year. Further observations are required to determine if the water table has reached an equilibrium level already, and if the moisture content will continue to decline.

- Intensive drainage methods, such as those under evaluation at St. Shotts and Markland, are likely to result in shortened drainage periods being required prior to the operational phase of peatland development. Unless the drainage period can be reduced sufficiently such that the total expenditure during the drainage period is less than the expenditure associated with standard 20 meter ditch spacing, then it is not feasible to go beyond the standard.

- With only two years of data from the St. Shotts site and one year from the Markland site, it is not possible to draw any firm conclusions as to the type of drainage systems that might be necessary for Newfoundland's conditions. It normally takes 5-7 years of drainage to drain blanket bogs.

These sites should be left to drain and monitoring must continue to provide the additional database necessary to draw the right conclusions. However, it is apparent from the data collected to date that the southern Avalon peninsula is at the climatic limitation for conventional sod peat harvesting tendencies.

- The continuation of the present drainage trials on the controlled sites presents a unique opportunity to collect long term drainage data and to study the drainage characteristics of two very different peat deposits. It will provide long term drainage information for the orderly development of peatlands.

6.2 Recommendations

The major recommendation of this report is that the monitoring of the drainage on the two controlled sites be continued for at least another three years. The program should be expanded to carry out operational trials on the various width fields to evaluate the effects on drainage of conventional activities such as profiling, extruding of peat and the subsequent harvesting of the peat.

The following study proposal is recommended as part of the on going activities for the monitoring program on these experimental drainage sites.

6.2.1 Study Proposal for 1989

Hydrological data for the post-drainage period have clearly shown that significant drainage has occurred on 5 and 10 m drainage fields, but that most of that drainage occurred during the months immediately following ditching. It is possible that a state of equilibrium has been reached, or is being approached, in terms of water table level and moisture content during summers with normal amounts of rainfall. On the other hand, further drainage is required to lower the moisture content of the in situ peat, and this process may be occurring at a rate undetectable by periodic measurements of hydrological variables. In order to determine the ongoing changes, an intensive monitoring of the hydrological variables in representative sites in the drained fields and virgin bog are required. This is important in determining the exact role of various ditch spacing scenarios, relative to evaporative and seepage losses. A more rigorous approach to the bog hydrology will provide a clear understanding of the processes of water transfer, and its relation to the bearing capacity and trafficability of drained soils. This type of knowledge is essential in planning future drainage operations, because it will allow confident recommendations to be made on ditch spacing and depth, rather than the present method of trial and error. Installation of the requisite instrumentation is relatively inexpensive, and when complimented by a more intensive parameterization of the watershed, will provide scientifically sound results which have implications for peat research nationally and internationally. Furthermore, the proposed study will operate concurrently with a larger more detailed hydrological study of a nearby natural peatland, being carried out independently by Dr. Jonathan Price (Memorial University). The results of these two studies can be interfaced to make a major contribution to the discipline.

The proposed study will be based around the present set of groundwater observation wells and soil moisture sampling sites. Continuous recording of the groundwater levels will be made at the centre field position of the 5 and 20 m ditched areas. Manual measurements of groundwater observation wells at other 5, 10 and 20 m field sites and at the virgin bog will be linked to these recording wells by regression analysis (see Price and Woo 1988). Soil moisture probes will be placed at a level of 30 cm below the surface at centre field of a 5, 10, and 20 m site. This will be used to determine the influence of water table fluctuations on the soil moisture content. One further recording well on the outflow stream to monitor discharge from the entire field will be complimented by manual staff gauges in a ditch within each of the 5, 10, and 20 m fields, so that their outflow can be estimated.

A series of multi-level piezometers will be installed in the peat and in the underlying mineral soil to determine the rate and direction of groundwater seepage. This will reveal the importance (if any) of lateral seepage through the mineral soil to the ditches, and the seepage loss (or gain) from deep groundwater.

The other important vertical fluxes are rainfall and evaporation. A tipping bucket rain gauge will be used to monitor on-site rainfall. This may be considerably different from the daily weather station data in the town of St Shotts. Evaporation will be estimated using the Priestley-Taylor combination model (see Price and Woo 1988). This requires hourly net radiation, ground heat flux and temperature data, which will all be measured on site. An electronic datalogger will be wired to water level, soil moisture, and evaporation sensors to process and store the information.

Further parameterization of the peat soil is required. Vertical profiles of hydraulic conductivity and specific yield will be made for all sites. The spatial distribution of hydraulic conductivity also needs further refinement.

7.0 REFERENCES

Barber, K.E., 1981. *Peat stratigraphy and climatic changes*. Balkema, Rotterdam, 219 pp.

Bay, R.R., 1969. Runoff from small peatland watersheds. *Journal of Hydrology*, 9: 90-102.

Boelter, D.H., 1972. Methods for analyzing the hydrological characteristics of organic soils in marsh ridden areas. *Proc. Minsk Symp.*, UNESCO Press = IAHS, Paris, 1975, 161-169.

Boelter, D.H., 1972. Water table drawdown around an open ditch in organic soils. *J. Hydrol.*, 15: 329-340.

Burke, W., 1961. Drainage investigation on bogland: the effects of drain spacing on ground water levels. *In. J. Agric. Res.*, 1: 31-34.

Damman, A.W.H., 1983. An ecological subdivision of the island of Newfoundland. In G.R. South (ed.), *Biogeography and Ecology of the Island of Newfoundland*. Junk, The Hague, 163-205.

Davis, A.M., 1989. Unpublished data. Dept. of Geography, University of Toronto. Personal communication.

Davis, A.M., 1984. Ombrotrophic peatlands in Newfoundland, Canada; their origins, development and trans-Atlantic affinities. *Chemical Geology*, 44: 287-309.

Davis, A.M., and Wickham, 1987. The microstratigraphy of two peat sequences from Northeastern Newfoundland. *Geographie Physique et Quaternaire*, 41: 355-364.

Downey, J.F., Report on uses of peat to the Minister of Agriculture and Mines (St. John's, Newfoundland: Government of Newfoundland, 1909), Newfoundland Provincial Archives, Ref. No. GN 2/5 (4A).

Engstrom, D.R. and Hansen, B.C.S., 1985. Postglacial vegetation change and soil development in southeastern Labrador as inferred from pollen and chemical stratigraphy. *Can. J. Bot.*, 63: 543-561.

Hafsten, U. and Solem, T., 1976. Age, origin, and paleoecological evidence of blanket bogs in Nord-Trondelag, Norway. *Boreas*, 5: 119-141.

Hare, F.K., 1952. *The Climate of the Island of Newfoundland; A Geographical Analysis*. Canada Department of Mines and Technical Surveys, Geographical Branch, Ottawa. Geographical Bulletin No. 2, pp. 36-88.

Ingram H.A.P., 1983. Hydrology. In A. J. P. Gore (ed.), *Mires: Swamp, Bog Fen and Moor*. Elsevier Scientific, New York, 67-158.

Ivanov, K.E., 1981. *Water Movement in Mirelands*. Thomson, A. and H.A.P. Ingram (trans.). Academic Press, London, 276 pp.

Monenco Ltd., 1981. *Peat in Ontario*.

Moore, P.D., Merryfield, D.L. and Price, M.D.R., 1984. The vegetation and development of blanket mires. In P.D. Moore (ed.), *European Mires*. Academic Press, London, 203-235.

Mulqueen, J., 1986. Hydrology and drainage of peatland. *Environ. Geol. Water Sci*, 9: 15-22.

Northland Associates Ltd., 1985. *St. Shotts' Sod Peat Demonstration Project.*. Energy, Mines and Resources Canada, St. John's, Newfoundland.

Northland Associates Ltd., 1978-83. *Peatland Inventory of Newfoundland*. Department of Mines and Energy, St. John's, Newfoundland.

Noval Technologies Ltd., 1985. *Bishop's Falls Milled Peat Mining Project*. Department of Mines and Energy, St. John's, Newfoundland. Report No. CR85-70.

Paivanen, J. and J. Taipale, 1980. Drainage technique for milled peat harvesting sites. *Proceedings 6th International Peat Congress*, Duluth, Minn., 286-290.

Payette, S., 1984. Peat inception and climatic change in northern Quebec. In N.A. Morner and W. Karlen (eds.), *Climatic Changes on a Yearly and Millenial Basis*. Reidel, Dordrecht, 173-179.

Price, J.S. and M.K. Woo, 1988. Studies of a subarctic coastal marsh. *I. Hydrology, J. Hydrol.*, **103**: 275-292.

Price, J.S., and J.E. FitzGibbon, 1987. Groundwater storage and streamflow in a subarctic wetland, Saskatchewan. *Canadian Journal of Earth Science*, **24**: 2074-2081.

Price, J.S. and J.E. FitzGibbon, 1982. Winter hydrology of a forested drainage basin. *Proceedings of the Canadian Hydrology Symposium*, Fredericton, New Brunswick, 347-348.

Rayment, A.F. and J.A. Campbell. *The influence of different drainage techniques on water outflow, soil aeration and crop growth on a Newfoundland peat soil, 1980*. Agriculture Canada, St. John's, Newfoundland.

Solem, T., 1986. Age, origin and development of blanket bogs in SorTrondelag, Central Norway. *Boreas*, **15**: 101-115.

Taylor, J.A. and Smith, R.T., 1980. The role of pedogenic factors in the initiation of peat formation and the classification of mires. *Proc. 6th Int. Peat. Congress*, 471-484.

Tolonen, K. Huttunen, P. and Jungner H., 1985. Regeneration of two coastal raised bogs in eastern North America. *Annales Academiae Scientiarum Fennicae Series A III Geologica-geographics* #139 51 pp.

Ugolini, F.C. and Mann, D.H., 1979. Biopedological origin of peatlands in southeast 'Alaska'. *Nature*, **256**: 482-484.

Vardy, R.B., 1987. *An integrated approach to resource development analysis: A study of the fuel peat resources of southeastern Newfoundland*. Masters thesis, Memorial University of Newfoundlnad, 338 pp.

Verry, E.S., D.H. Boelter, 1978. Peatland hydrology. *Proceedings of the National Symposium on Wetlands*, Lake Buena Vista, 389-402.

Wells, D., 1981. Peatlands of eastern Newfoundland: distribution, morphology, vegetation and nutrient status. *Can. J. Bot.*, **59**: 1978-1997.

Wells, E.D. and R.B. Vardy, 1981. Peat resources of Newfoundland with emphasis on its use for fuel. *Proc. of I.G.T. Symposium "Peat as an energy alternative"*, Arlington, Va., Dec. 1-3, 1980, 679-697.

APPENDIX 1

Geotechnical Investigations of Peatlands at St. Shotts and Markland, Newfoundland

Prepared for:

Northland Associates Limited

February 1, 1987

Dr. Arvid Landva
Dept. of Engineering
University of New Brunswick

Geotechnical Investigations of Peatlands at St. Shotts and Markland, Newfoundland

The preliminary phase of the geotechnical investigations of the St. Shotts' and Markland's peatlands has been completed. The field work was carried out during July and August, 1987, and the laboratory work has been carried out intermittently from September 1987 to February 1988.

The results of our field work are presented in figures 1-14. Figures 15-18 show the results of the geotechnical laboratory tests.

Figure 1 is a diagrammatic sketch of the zones of the influence under various loads (under PLT-500, PLT-10,000 and tractor tire).

> **Note:** PLT-500 = plate load test with 500 cm^2 plate, PLT-4,000 = ditto with 4,000 cm^2 plate etc. The tractor tire in figure 1 is shown to the same scale as the plates.

Figures 2-10 are the results of various load tests. Different tests are grouped for purposes of comparison—for example, tests on the intact mat and test on the mat after cutting it around the test plate.

Figures 11-13 are diagrammatic sketches of actual load tests on the mat (cut and intact).

Figure 14 displays the bearing pressures under different types of equipment. Since the bearing pressure q is directly dependent on the sinkage of the tires or drums, q is given as a function of the sinkage (2-20 cm or about 1: to 8: assumed). Superimposed on these curves are the results of the tire plate load test (which strictly applies only to the tractor front tires, since the tire plate was modelled after that size tire).

Figures 15-17 are graphical summaries of the geotechnical laboratory tests (consolidation, permeability, ring shear, and lateral stress/strength tests).

Figure 18 is a graphical summary of a model load test.

The geotechnical properties of peat are typically quite variable and erratic. The current investigation was directed therefore towards attempting to predict the behaviour of the peat under different imposed loading conditions and towards disclosing the behaviour of the peat under actual field conditions.

Certain trends are evident from the 1987 field investigations:

- Most of the bearing capacity is supplied by the upper 10-20 cm of the peat, i.e. by the living mat. (Not generally true; see below).
- It takes a very large deformation to fail the living mat.
- The strength of the mat decreases with an increasing number of passes of heavy equipment. The more aggressive the traction is, the faster the mat will deteriorate.
- It is difficult to predict the presence of soft areas, unless the mat is virtually absent.

- It is difficult to predict firm areas, as distinct from medium firm or medium soft areas.

- The lowest bearing capacity measured was about 20 kPa and the highest about 250 kPa—a very large range.

Upon further analysis these trends still appear to be true, except that the contribution from the mat seems to be much smaller than originally assumed. Both at St. Shotts and at Markland the mat seems to contribute little strength directly to the bearing capacity depending on the amount of sinkage of the bearing surface. The two main reasons for this are (i) that the mat at these locations is comparatively thin (10-20 cm), and (ii) that the degree of stretching required to mobilize the strength of the mat is very high - much higher than in the case of the underlying fibrous sedge peat. On the other hand, it is thought that the mat does have an important function that would contribute to the bearing capacity: it may provide a natural drainage filter between the much less pervious underlying peat and the applied load. This assumption is paraphrased below:

It is a generally acknowledged fact that the ground water has a significant effect on the bearing capacity. In geotechnical terms, this is so because the application of a load sets up pore water pressures in the ground. The higher the ground water level is, the higher will be the pore pressures. A large amount of compression in the peat takes place instantaneously, i.e. during loading, and the more water there is in the peat, the more water will attempt to escape. As the peat compresses, its hydraulic conductivity may also decrease considerably, depending on the compressibility of the peat, and it becomes therefore more difficult for the water to escape. If the loading boundary is water-tight, as it is under a rubber tire or a steel drum, no water can escape upwards, and the dissipation of pore pressure is therefore delayed. Since the water carries part of the load from the equipment, and since water has no strength, this is a critical stage of the load cycle. Considering also that the entire load cycle can take as little as fractions of a second (if the equipment is moving), it is evident that it is important to dissipate the water pressure without delay.

The main purpose of the preliminary geotechnical investigations at St. Shotts and Markland has been to attempt to devise a test or group of tests that can be used to predict the bearing capacity of the peatland with respect to harvesting equipment. During normal seasons, these peat bogs are quite wet, and equipment readily becomes bogged down. Proper drainage improves these conditions, and the task then is to determine at what stage the bearing capacity has become sufficient to support the harvesting equipment.

The 1987 field investigations were carried out during an exceptionally dry season and so are not representative of the "normal" situation. On the other hand, they did provide us with an opportunity to observe some of the equipment in action and to obtain some weights and dimensions of most of the equipment. These measurements are compiled graphically in Figure 14. They show that the maximum actual pressures under the equipment is in the vicinity of 60 kPA (about 1,250 psf), allowing for some sinkage of the tires or drums. For example, the contact pressure under the rear double tractor tires is about 60 kPa if they sink 6 cm (about 2 1\2") into the bog. The corresponding pressure under the front tires would be about the same for 6 cm sinkage, but would decrease to 34 kPa (about 700 psf) if the tires sank 20 cm (8") into the bog (which they actually did during one overnight parking period). The pressure under the backhoe tracks is surprisingly low: about 23 kPa or 480 psf. And if the front tractor tires are doubled, the contact pressure decreases to 20 kPa (585 psf) at 6 cm (2 1/2") sinkage. The screw leveller pressures are low at all values of sinkage (max 30 kPa or 625 psf).

The pressures under the front drum of the harvester were calculated on the basis of the load on the drum when the harvester was detached from the tractor. This is not representative of the actual conditions, i.e. the conditions prevailing when the harvester is attached to the tractor. For example, in the case of little or no sinkage of the tractor, the front drum apparently does not even touch the ground. On the other hand, the rear end of the tractor may sink in sufficiently that the front drum is forced into the bog, in which case it would be carrying a considerable portion of the total load. It is our understanding that this action could actually cause the equipment to become bogged down because of the resulting plowing action of the front drum.

There are several conditions of loading and states of the bog that have to be considered for an evaluation of bearing capacity:

- Static loading, such as parking (Figure 2).

- Moving loads, no traction.

- Moving loads, full traction.

- Repetitive loading.

- Virgin bog surface.

- Surface (mat) breakdown due to traffic (Figure 7).
- Location of soft areas.
- Type of equipment (tires, drums, different types of tracks).
- Type of traffic (straight, turning, kneading, stopping).
- Effects of slicing (cutting), e.g. direct effects by removing lateral support, and indirect effects by collecting undrained water.
- Effects of drainage, controlled and natural.

There can be little doubt that the single best remedy to any of the problems associated with these various conditions is drainage. In geotechnical terms, drainage is synonymous with reduced porewater pressures. When ever the porewater pressures are reduced, the bearing capacity will increase, because more of the applied pressures will be carried by the peat structure itself. In cases where the peat structure is strong, the bearing capacity will be relatively high. However, if the peat structure is exceptionally porous and hence very compressible, the bearing capacity will be lower. For example, in the cases of "soft spots", the peat structure is no doubt "exceptionally porous", and a very low bearing capacity will be the result if the area is not drained. If drained, the bearing capacity will be much higher, but initial sinkage (i.e. sinkage during the first few passes) will probably be relatively high.

It is our understanding that, even during a normal (wet) season, problems are encountered locally rather than across the entire field. For example, a combination of items 3, 4, 6, 7, 8, 9 and 10 above would almost certainly result in predictable problems. It is conceivable that such problems could be minimized through drainage of the soft areas and by using the least aggressive type of equipment (for example the "Martin" track?). In regard to item 10, it is probable that the detrimental effects of slicing and cutting could be reduced considerably by drainage. The main problem here would appear to be a collection of free water in the sliced channels at the lower part of the field, and this free, surplus water would tend to mix with the surrounding peat as a result of the kneading action of the turning equipment. This kneading action is more critical in the sliced areas because of the reduction of the lateral support of the peat to considerable depth.

The profiling of the fields, including the shallow secondary ditch in the central high protein between the main (primary) ditches, may or may not result in any bearing capacity problems. No problems were apparent during the dry 1987 season, but this was not a representative condition. In any case, on the basis of our field and laboratory investigations, it would seem that the profiling itself should not cause any direct bearing capacity problems. The removal of part of the mat in the lower portion may not be critical for two reasons: (i) we have found that the mat contributes only a small portion to the bearing capacity for normal (not excessive) sinkage, and (ii) this area is well drained, being located next to the main ditch. The addition of fibrous material in the upper area (cuttings from the lower area) and also some drainage into the secondary ditch will contribute to the bearing capacity here. Thus if any problems were to arise in the profiled areas, they might be expected to occur in the area midway between the primary and secondary ditches where the ground water level would be at its highest.

Although firm conclusions cannot be drawn on the basis of an investigation during a dry season, we have nevertheless offered some above, and it may also be concluded that the prediction of bearing capacity cannot be made on the basis of one simple test such as a static plate load test. The most promising approach appears to be one of traversing the peat bog with a moving load and to measure sinkage as a function of the number of passes, starting with one pass and narrowing the area down with an increasing number of passes of softer spots. Further (standard) testing may then be carried out in the softer spots, e.g. static plate load testing (Bevameter testing), shear ring testing, Hiller sampling with classification, water content, organic content, and porewater pressure measurements including groundwater levels, depth of peat, etc.

The 1987 field investigations—in combination with the laboratory investigations of undisturbed samples—have proved to form a good basis for further investigations of the bearing capacity of peatlands subject to harvesting and associated modifications and traffic.

Our investigations have also indicated that, in addition to measuring the bearing capacity on the basis of the present harvesting techniques, considerations should also be given to changing and perhaps improving certain aspects of these techniques, for example the choice of chassis (tires, drums, tracks) and the identification of critical drainage areas.

LIST OF FIGURES

Figure 1 Diagrammatic sketch of the zones of influence under various loads (under PLT-500, PLT-4,000, PLT-10,000 and tractor tire).

Figure 2 PLT-500 on intact mat, PLT-4,000 on intact and cut mats, PLT-10,000 and tire plate test (22 x 70 cm), St. Shotts (all slow tests).

Figure 3 PLT-500 (slow) on surface and at 0.5 m depth, St. Shotts.

Figure 4 PLT-500 (quick) on surface and at 0.1 and 0.3 m depths, St. Shotts.

Figure 5 PLT-500 (slow) on intact and cut surfaces, in PLT-4,000 crater and at 0.5 m depth.

Figure 6 PLT-500 (quick) on surface after various depths, St. Shotts and Markland.

Figure 7 PLT-500 (quick) on surface after various number of passes of heavy equipment, St. Shotts and Markland.

Figure 8 PLT-500 (quick) on surface within apparently soft spots, St. Shotts and Markland.

Figure 9 PLT-500 (quick) on surface within apparently firm spots, St. Shotts and Markland.

Figure 10 PLT-500 (quick and slow) on intact mat, St. Shotts and Markland.

Figure 11 Probable deformation pattern under PLT-4,000 on mat, cut and intact, St. Shotts.

Figure 12 Behaviour of PLT-500 on cut mat, St. Shotts.

Figure 13 Behaviour of PLT-500 on mat within crater of PLT-4,000 on cut mat, St. Shott's.

Figure 14 Bearing pressures under different types of equipment as a function of the sinkage of the bearing area.

Figure 15 Permeability of the St. Shotts field 20-3 mat and peat as a function of the degree of compression (ev%) under load (pv).

Figure 16 Ring shear tests on peat from St. Shotts.

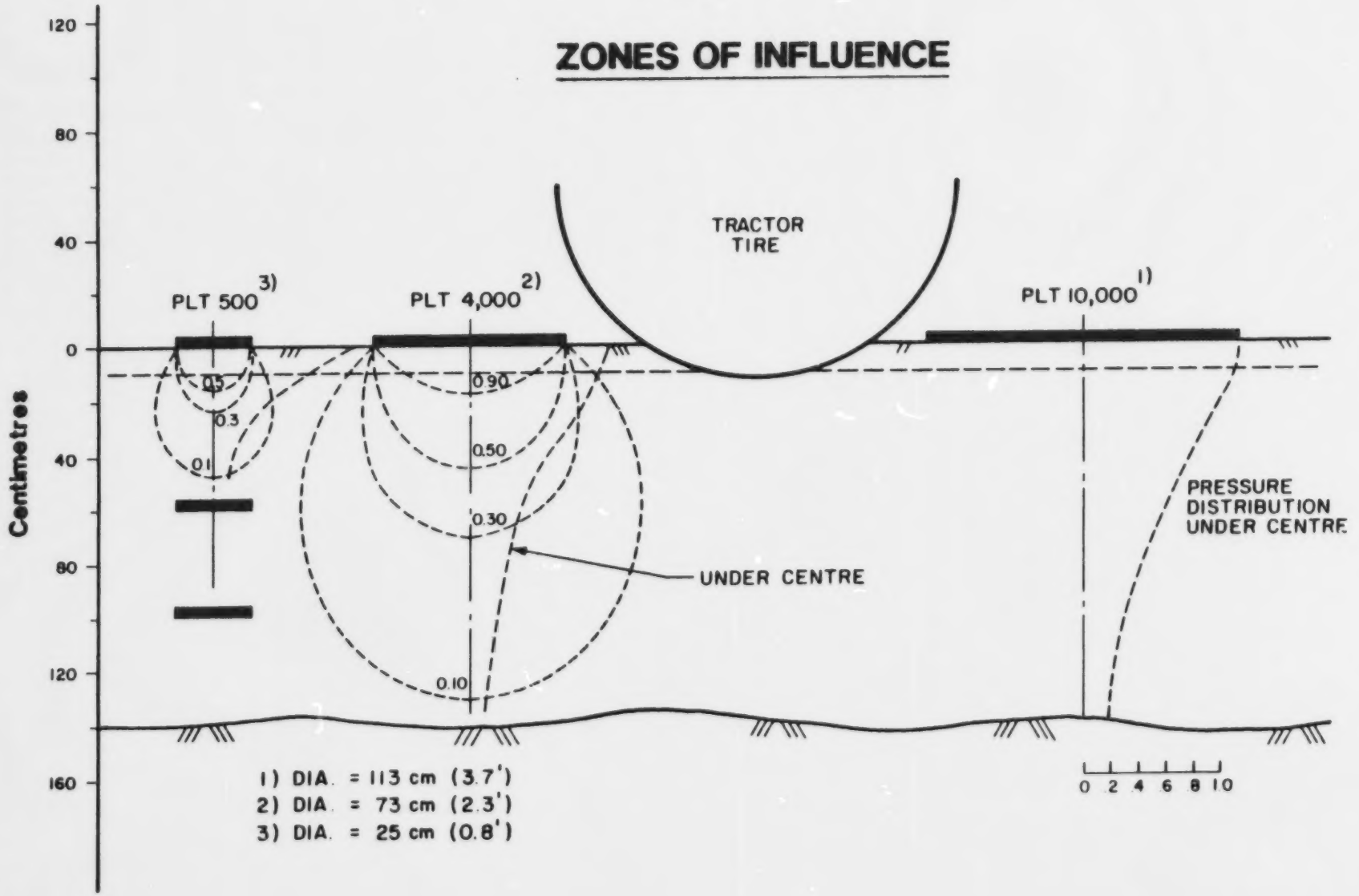
Figure 17a Lateral stress/strength tests on mat and peat from St. Shotts: lateral strength vs. vertical compressive (consolidation) stress.

Figure 17b Lateral stress/strength tests on mat and peat from St. Shotts: lateral stress vs. horizontal extension.

Figure 18a Model load test (=10 cm and 20 cm).

Figure 18b Model load test (= 20 cm).

Figure 1


ZONES OF INFLUENCE
TRACTOR TIRE
PLT 500 3)
PLT 4,000 2)
PLT 10,000 1)
Centimetres
120
80
40
0
40
80
120
160
0.5
0.3
0.1
0.90
0.50
0.30
0.10
UNDER CENTRE
PRESSURE DISTRIBUTION UNDER CENTRE
0 2 4 6 8 10
1) DIA. = 113 cm (3.7')
2) DIA. = 73 cm (2.3')
3) DIA. = 25 cm (0.8')

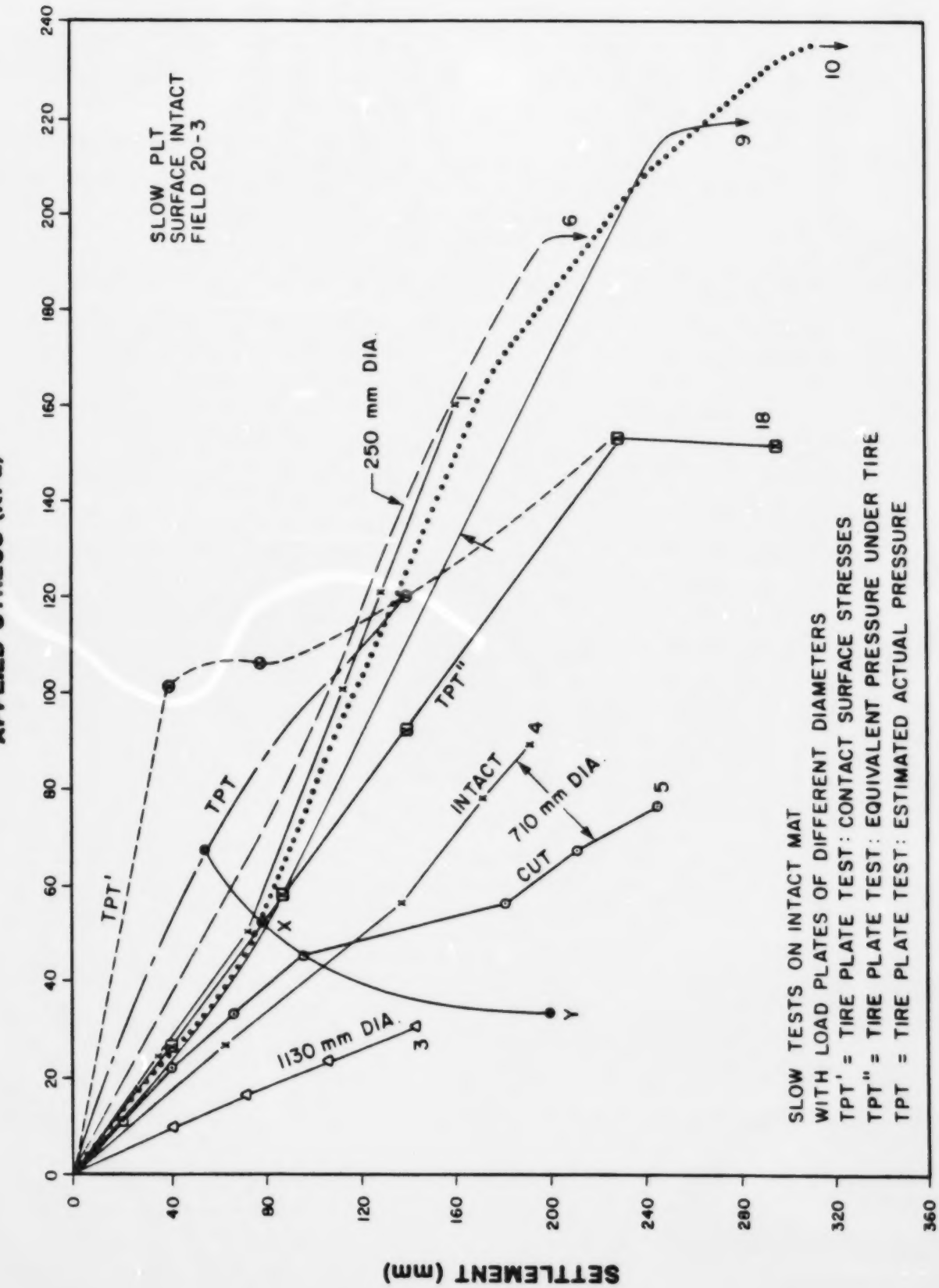

SLOW PLT
SURFACE INTACT
FIELD 20-3
APPLIED STRESS (KPa)
SETTLEMENT (mm)
0
20
40
60
80
100
120
140
160
180
200
220
240
0
40
80
120
160
200
240
280
320
360
TPT'
TPT
TPT"
250 mm DIA
1130 mm DIA
710 mm DIA
INTACT
CUT
X
Y
3
4
5
6
9
10
18
SLOW TESTS ON INTACT MAT
WITH LOAD PLATES OF DIFFERENT DIAMETERS
TPT' = TIRE PLATE TEST: CONTACT SURFACE STRESSES
TPT" = TIRE PLATE TEST: EQUIVALENT PRESSURE UNDER TIRE
TPT = TIRE PLATE TEST: ESTIMATED ACTUAL PRESSURE

Figure 2

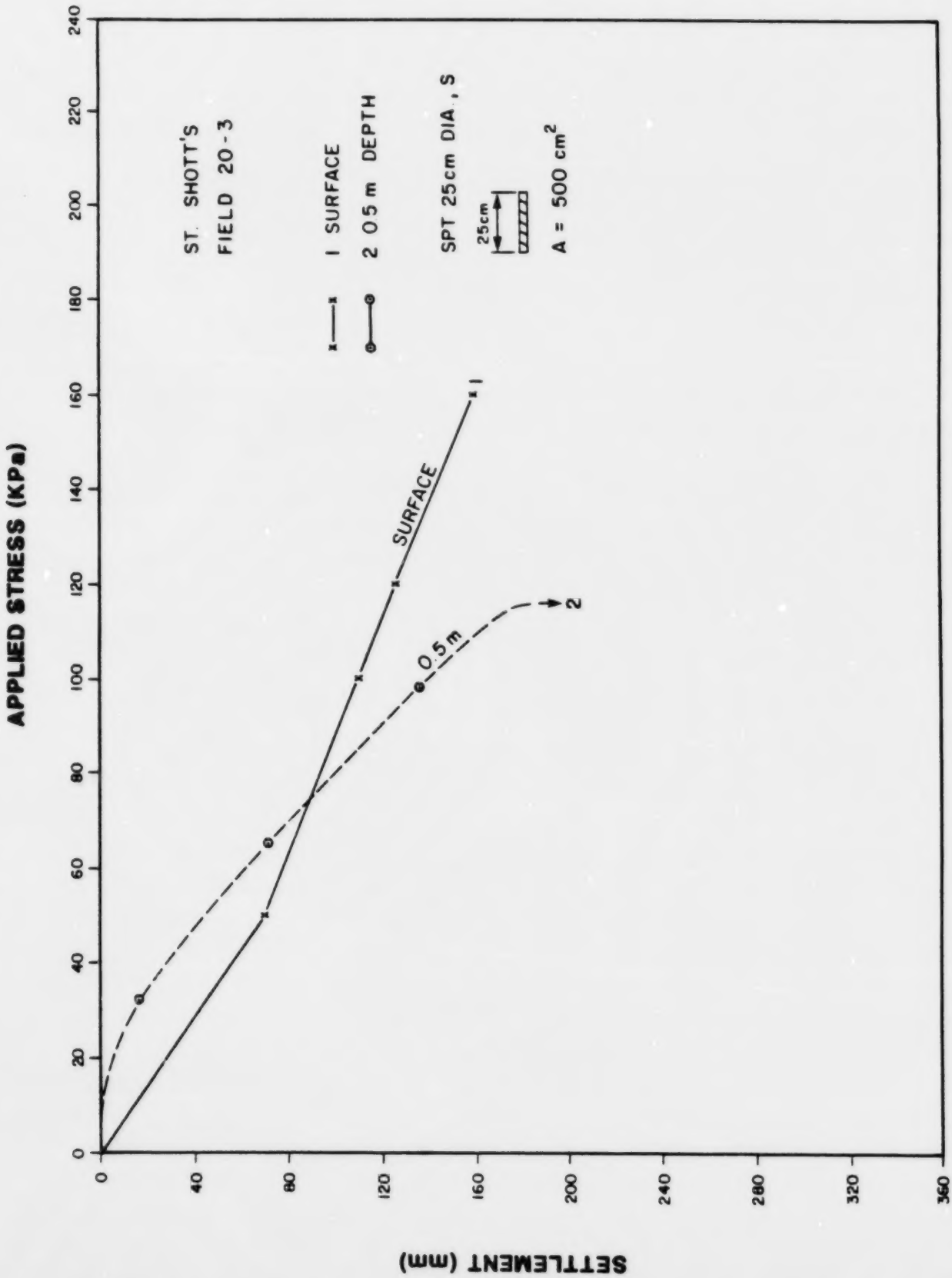

ST. SHOTT'S
FIELD 20-3
1 SURFACE
2 0.5 m DEPTH
SPT 25cm DIA., S
25cm
A = 500 cm²
SURFACE
0.5m
1
2
APPLIED STRESS (KPa)
SETTLEMENT (mm)
0
20
40
60
80
100
120
140
160
180
200
220
240
0
40
80
120
160
200
240
280
320
360

Figure 3

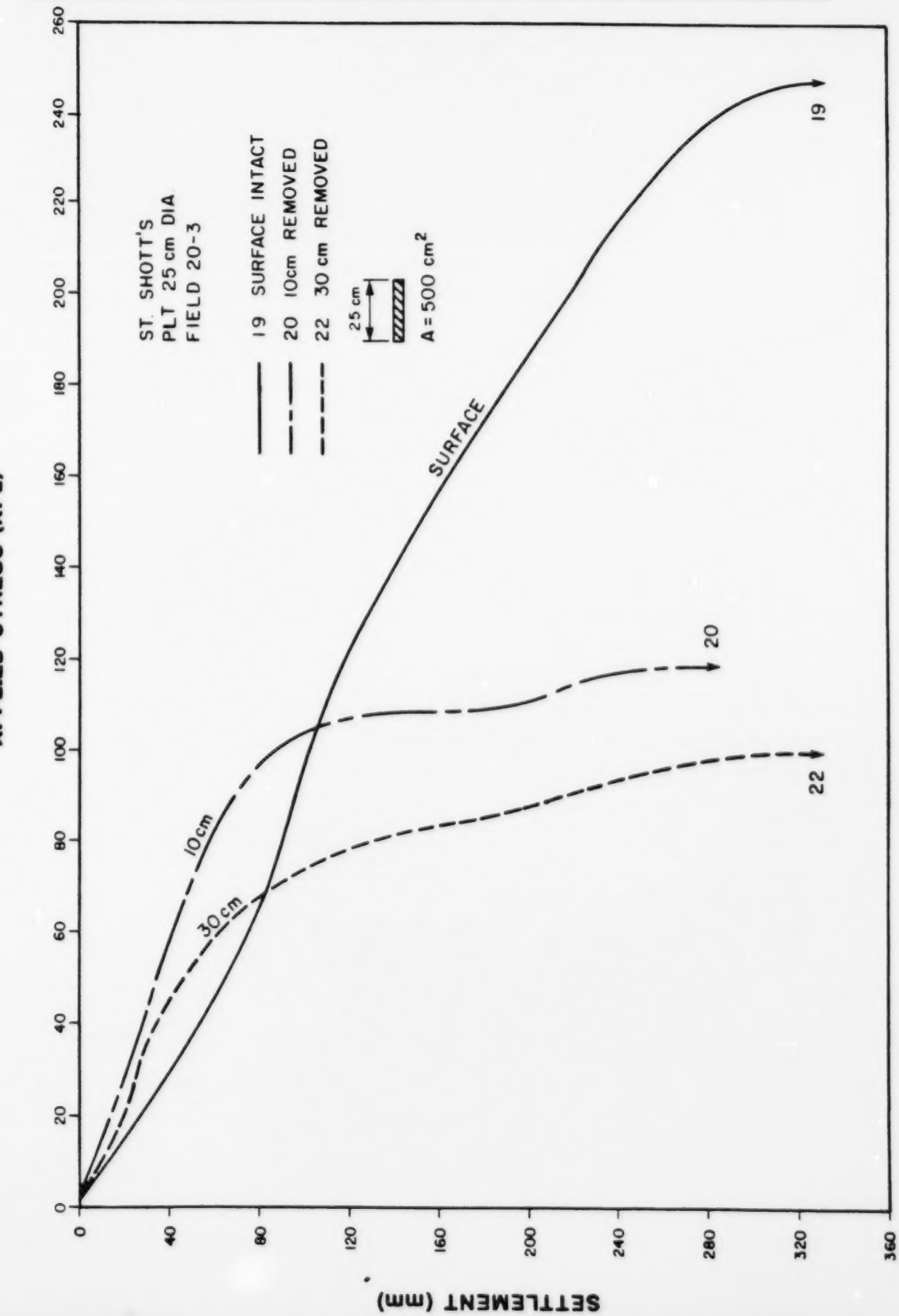

ST. SHOTT'S
PLT 25 cm DIA
FIELD 20-3
19 SURFACE INTACT
20 10cm REMOVED
22 30 cm REMOVED
25 cm
A = 500 cm²
SURFACE
10cm
30cm
19
20
22
APPLIED STRESS (KPa)
SETTLEMENT (mm)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
0
40
80
120
160
200
240
280
320
360

Figure 4

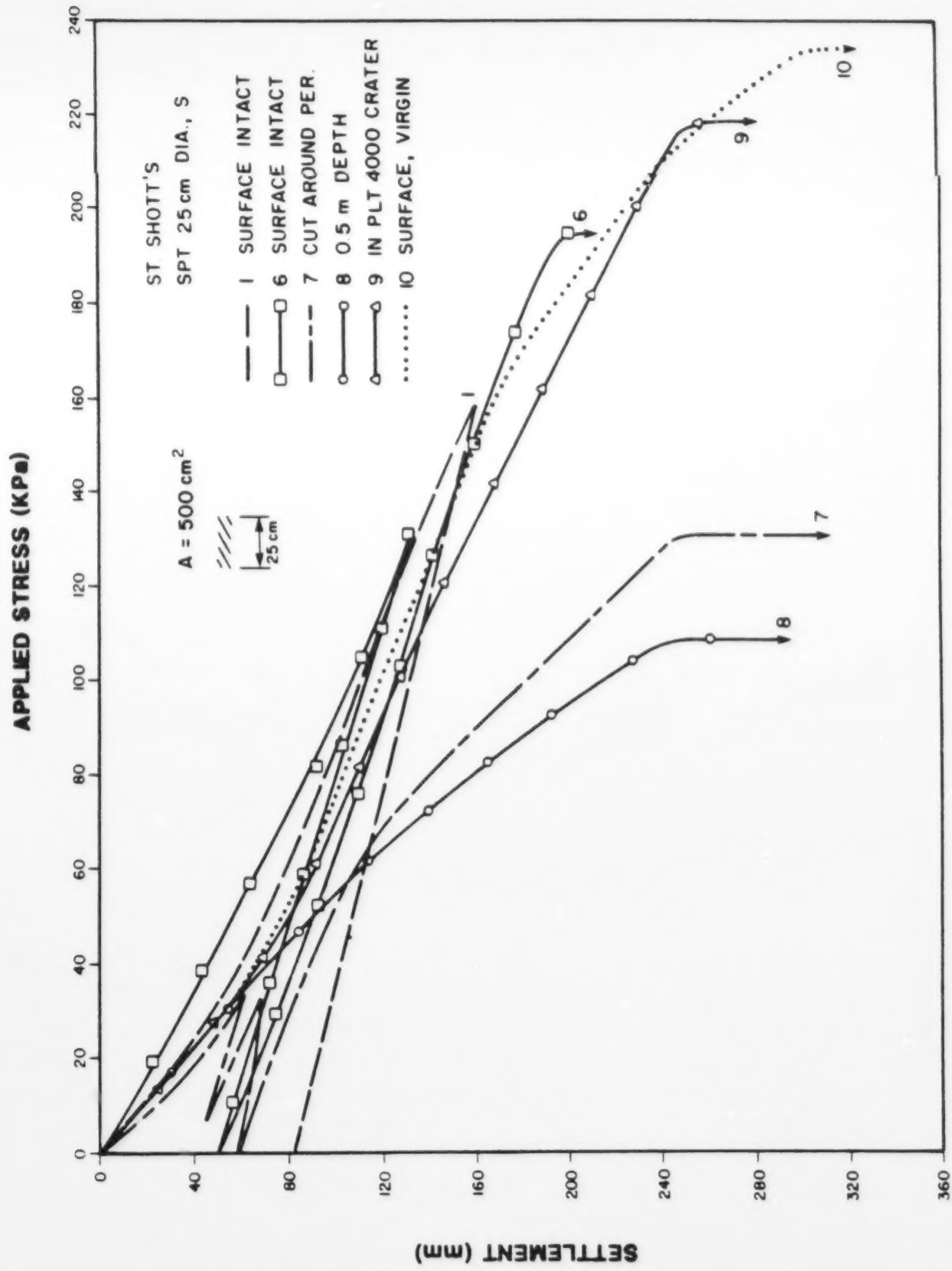

ST SHOTT'S
SPT 25 cm DIA., S
1 SURFACE INTACT
6 SURFACE INTACT
7 CUT AROUND PER.
8 0.5 m DEPTH
9 IN PLT 4000 CRATER
10 SURFACE, VIRGIN
A = 500 cm²
25 cm
APPLIED STRESS (KPa)
SETTLEMENT (mm)
0
20
40
60
80
100
120
140
160
180
200
220
240
40
80
120
160
200
240
280
320
360

Figure 5

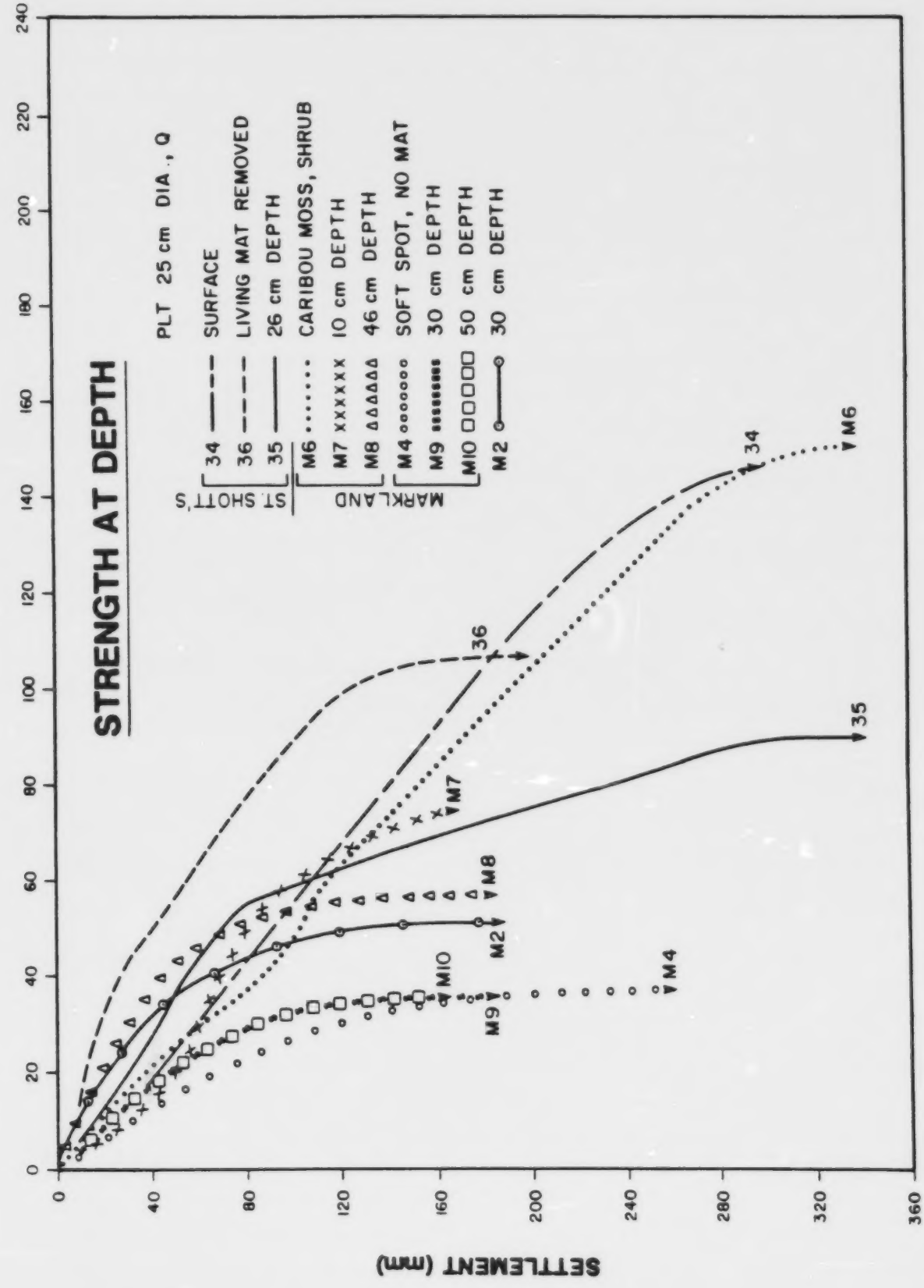

STRENGTH AT DEPTH
PLT 25 cm DIA., Q
ST. SHOTT'S
34 SURFACE
36 LIVING MAT REMOVED
35 26 cm DEPTH
MARKLAND
M6 CARIBOU MOSS, SHRUB
M7 10 cm DEPTH
M8 46 cm DEPTH
M4 SOFT SPOT, NO MAT
M9 30 cm DEPTH
M10 50 cm DEPTH
M2 30 cm DEPTH
APPLIED STRESS (KPa)
SETTLEMENT (mm)
0
20
40
60
80
100
120
140
160
180
200
220
240
0
40
80
120
160
200
240
280
320
360

Figure 6

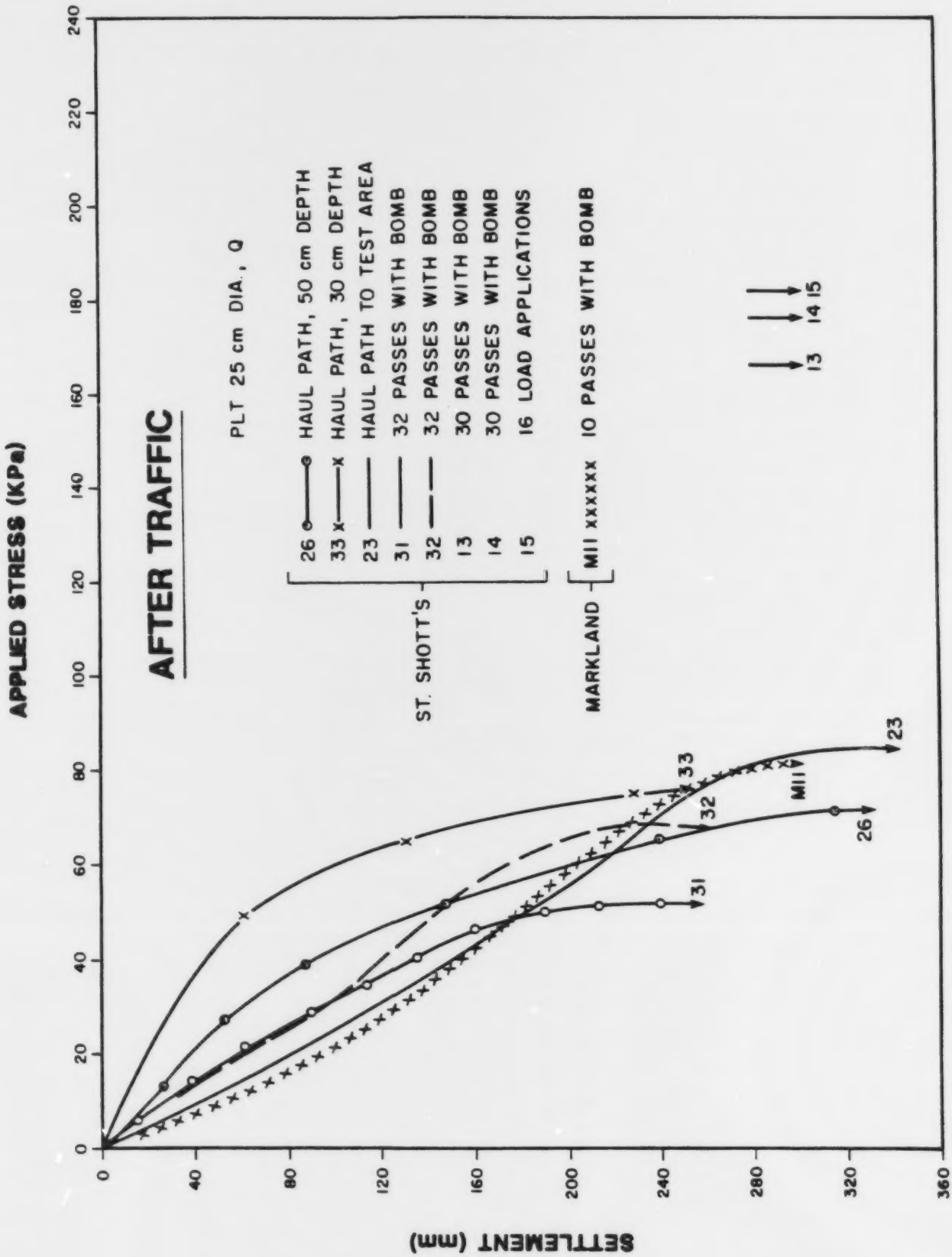

AFTER TRAFFIC
PLT 25 cm DIA., Q
ST. SHOTT'S
26 HAUL PATH, 50 cm DEPTH
33 HAUL PATH, 30 cm DEPTH
23 HAUL PATH TO TEST AREA
31 32 PASSES WITH BOMB
32 32 PASSES WITH BOMB
13 30 PASSES WITH BOMB
14 30 PASSES WITH BOMB
15 16 LOAD APPLICATIONS
MARKLAND
MII xxxxxx 10 PASSES WITH BOMB
13 14 15
APPLIED STRESS (KPa)
SETTLEMENT (mm)
0 20 40 60 80 100 120 140 160 180 200 220 240
0 40 80 120 160 200 240 280 320 360

Figure 7

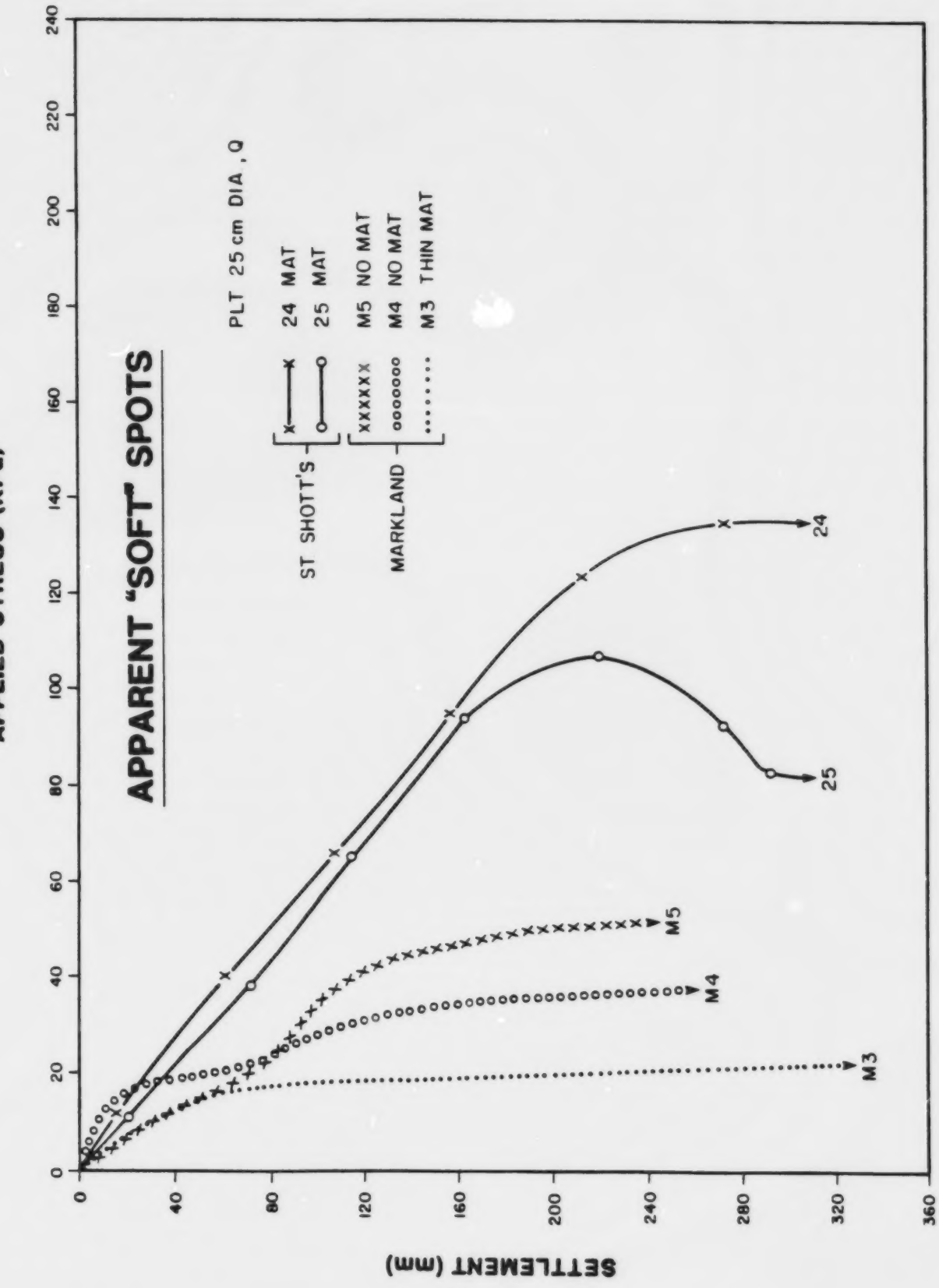
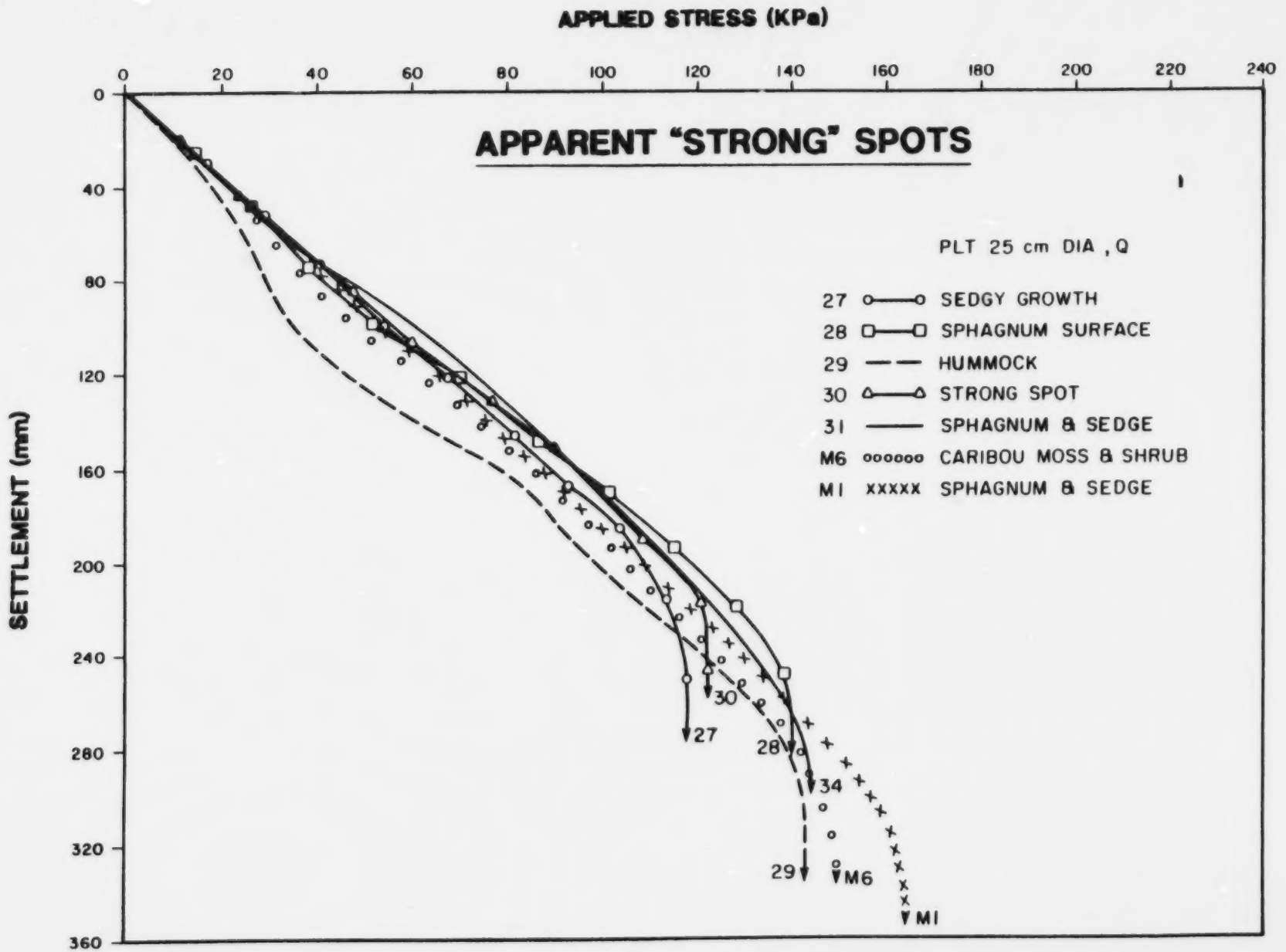

APPARENT "SOFT" SPOTS
PLT 25 cm DIA , Q
ST SHOTT'S
24 MAT
25 MAT
MARKLAND
M5 NO MAT
M4 NO MAT
M3 THIN MAT
APPLIED STRESS (KPa)
SETTLEMENT (mm)
0
20
40
60
80
100
120
140
160
180
200
220
240
0
40
80
120
160
200
240
280
320
360
24
25
M5
M4
M3

Figure 8

Figure 9


APPLIED STRESS (KPa)
0
20
40
60
80
100
120
140
160
180
200
220
240
APPARENT "STRONG" SPOTS
PLT 25 cm DIA , Q
27 SEDGY GROWTH
28 SPHAGNUM SURFACE
29 HUMMOCK
30 STRONG SPOT
31 SPHAGNUM & SEDGE
M6 CARIBOU MOSS & SHRUB
M1 SPHAGNUM & SEDGE
SETTLEMENT (mm)
0
40
80
120
160
200
240
280
320
360
27
28
30
34
29
M6
M1

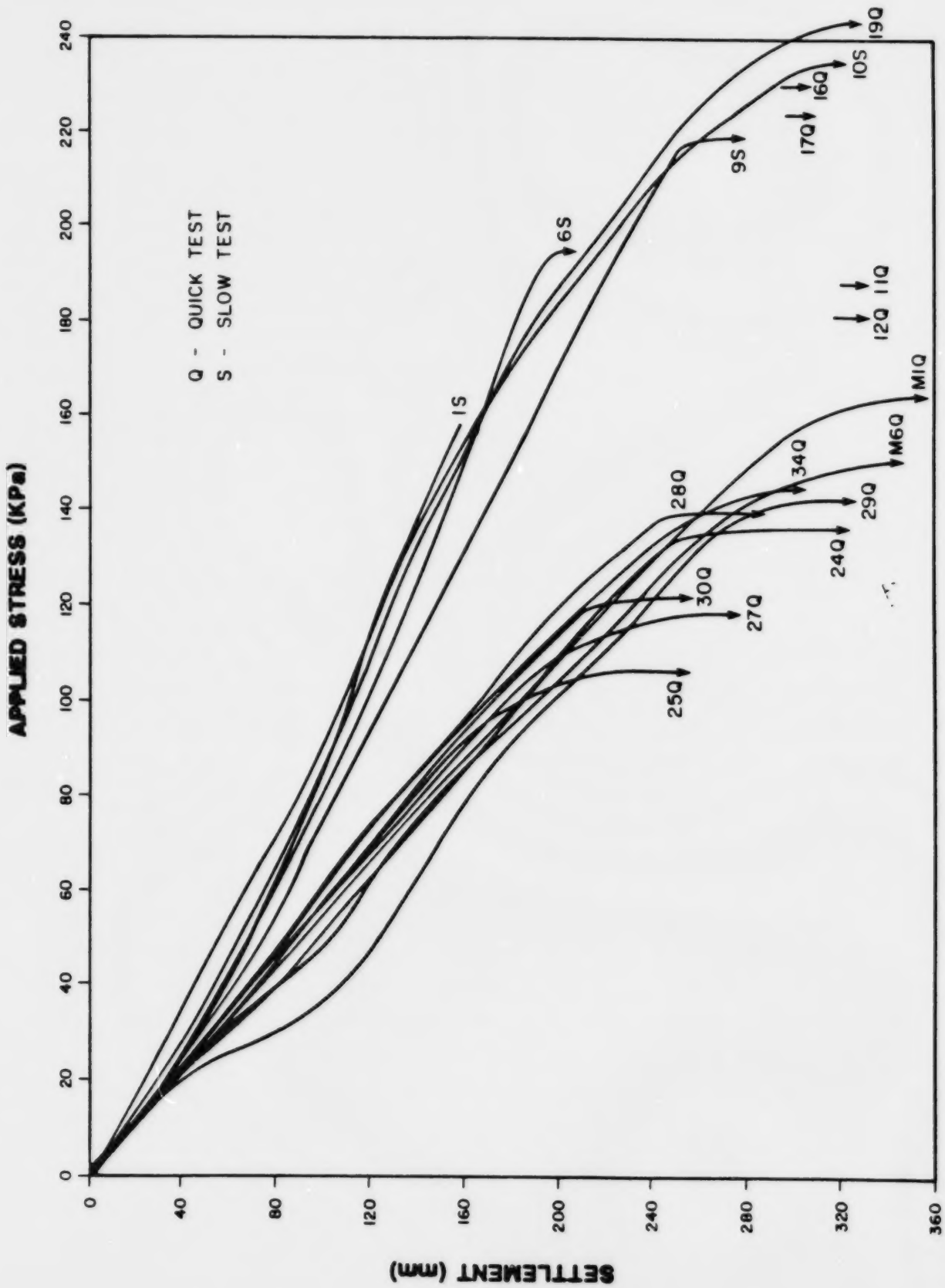
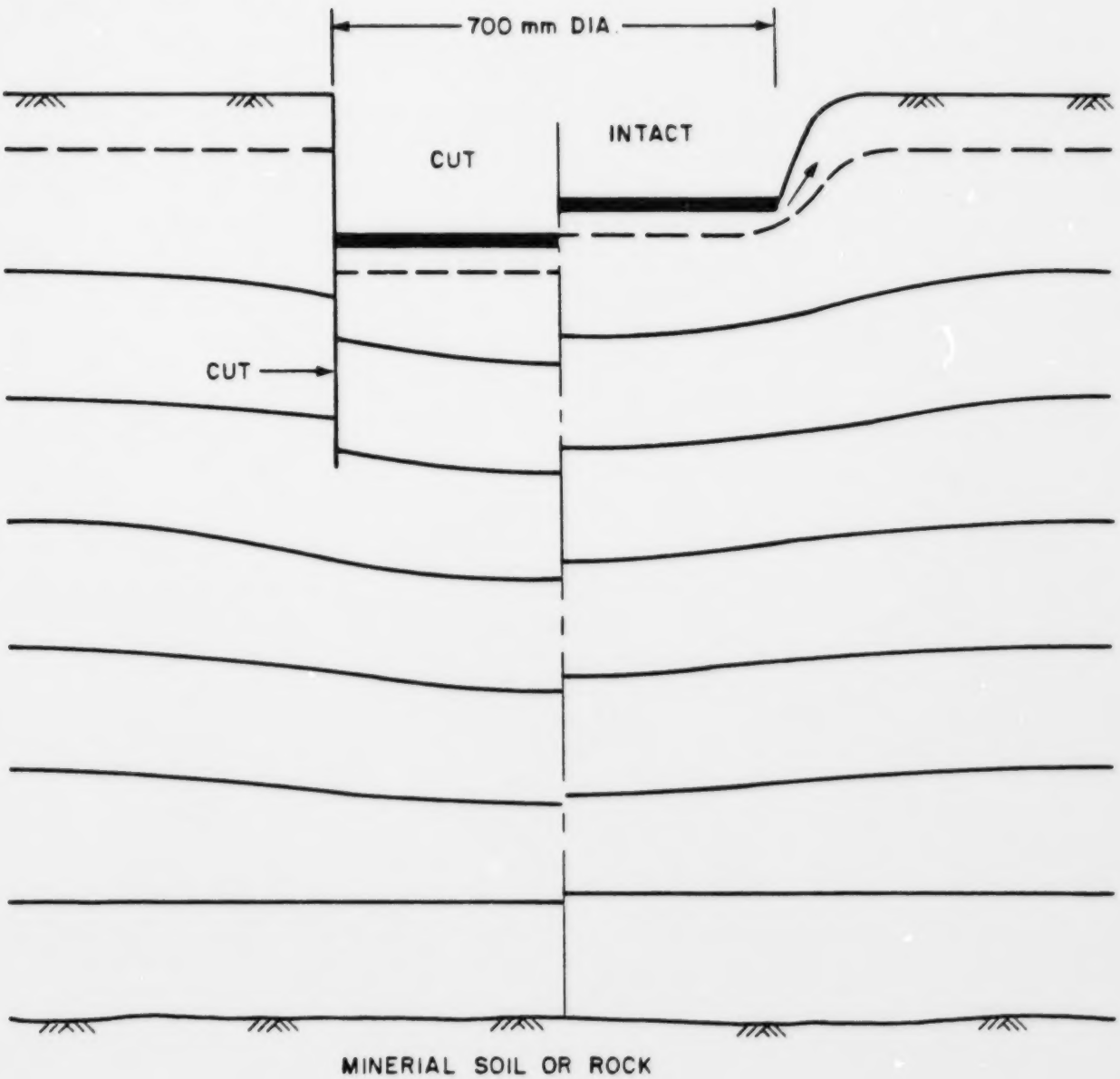

APPLIED STRESS (KPa)
SETTLEMENT (mm)
Q - QUICK TEST
S - SLOW TEST
1S
6S
9S
10S
19Q
16Q
17Q
12Q 11Q
MIQ
M6Q
34Q
28Q
29Q
24Q
30Q
27Q
25Q

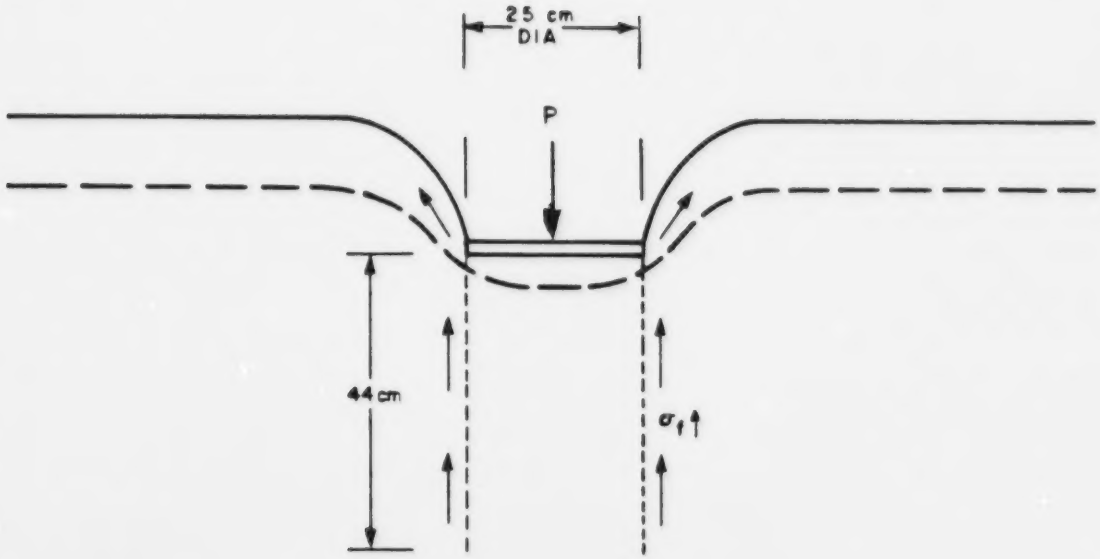
Figure 10

Figure 11



PLT - 4000 ON MAT, ST. SHOTT'S : CUT & INTACT
PROBABLE DEFORMATION PATTERN

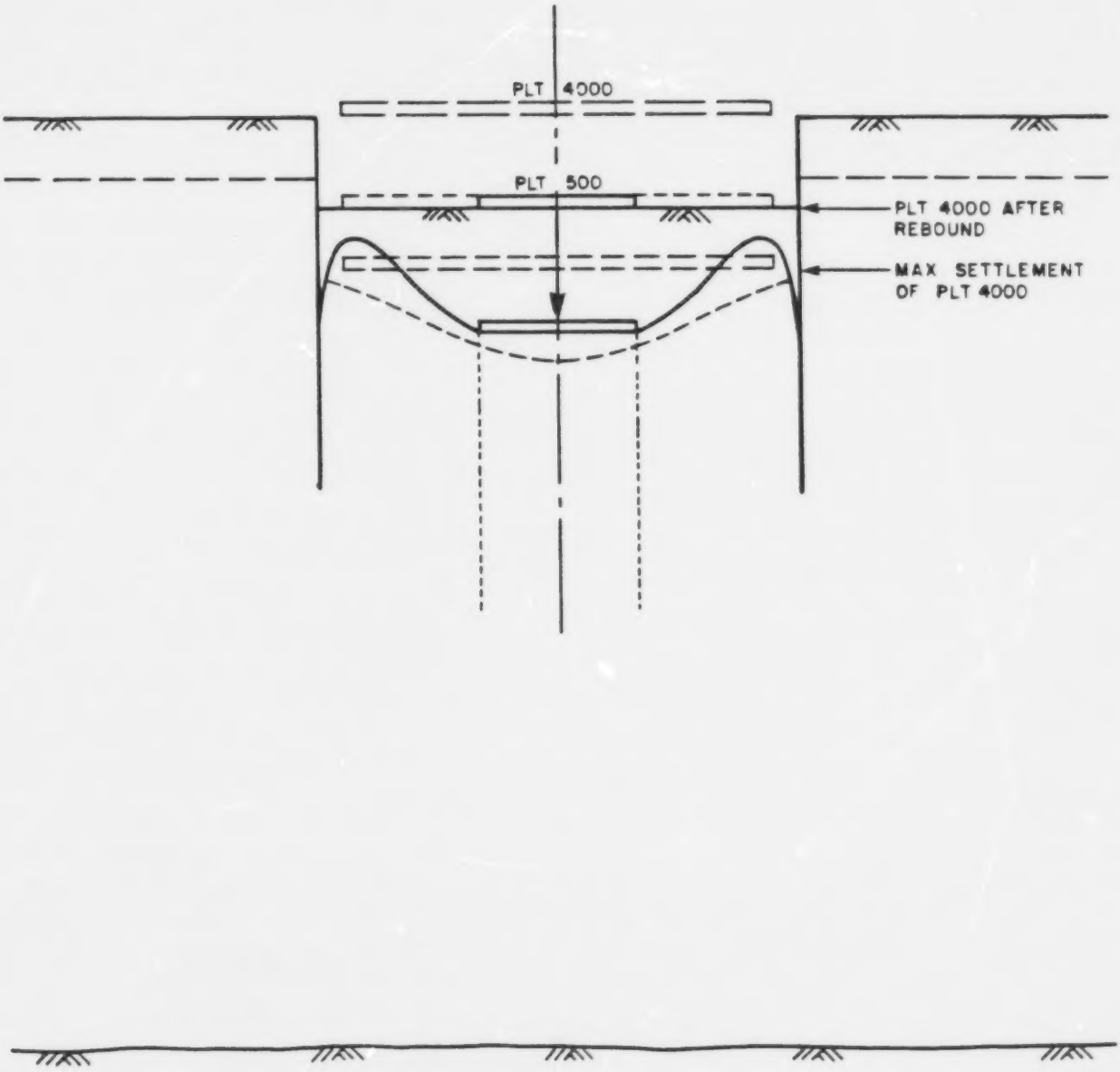
Figure 12



σ_f VERTICAL COMPONENT
OF PEAT FIBRE STRENGTH

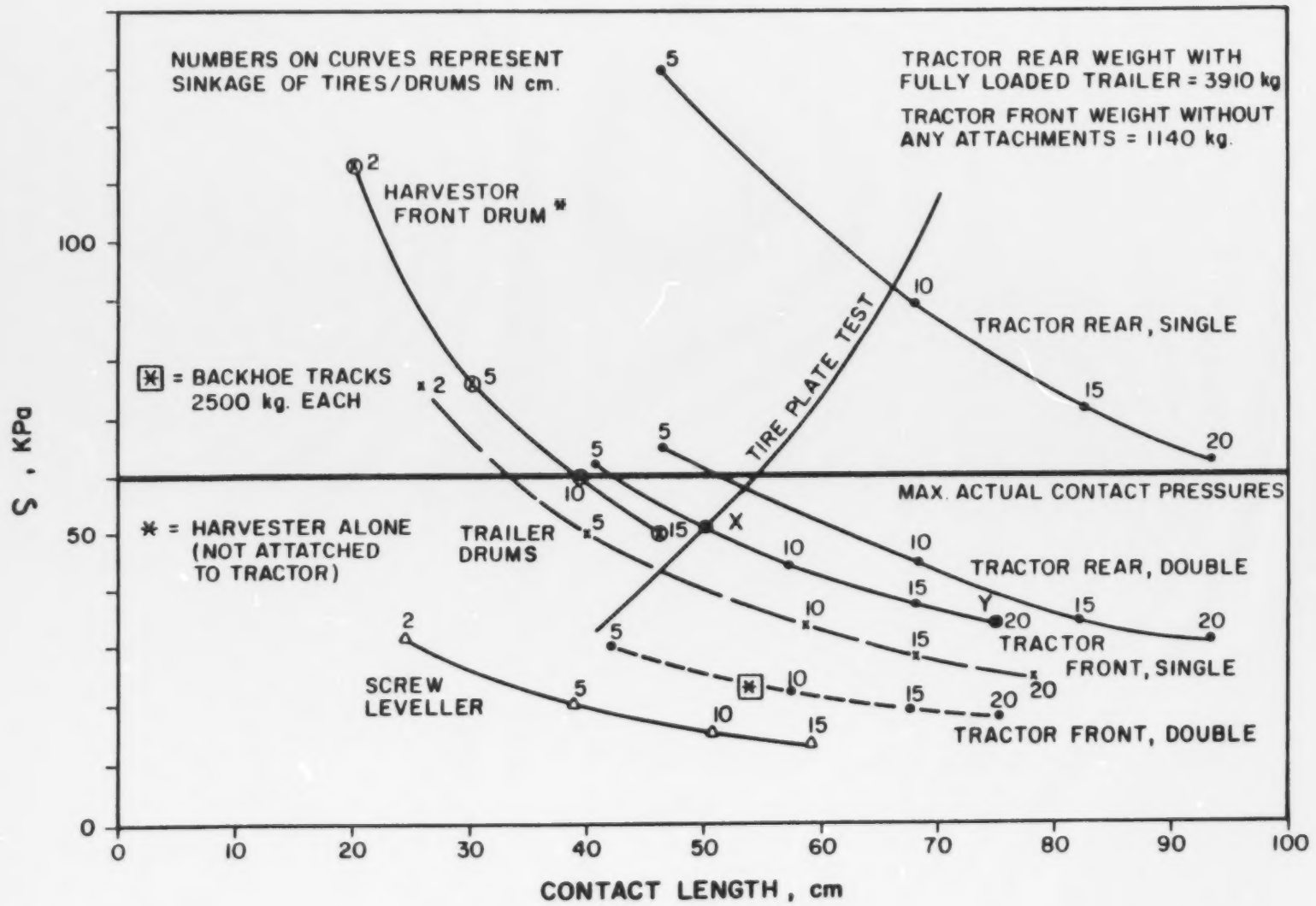
PLT-500 ON CUT MAT, ST. SHOTT'S

Figure 13



PLT-500 ON MAT IN CRATER OF PLT-4000 ON CUT MAT, ST. SHOTT'S

Figure 14


NUMBERS ON CURVES REPRESENT SINKAGE OF TIRES/DRUMS IN cm.
TRACTOR REAR WEIGHT WITH FULLY LOADED TRAILER = 3910 kg
TRACTOR FRONT WEIGHT WITHOUT ANY ATTACHMENTS = 1140 kg.
HARVESTOR FRONT DRUM *
TRACTOR REAR, SINGLE
TIRE PLATE TEST
⊠ = BACKHOE TRACKS 2500 kg. EACH
MAX. ACTUAL CONTACT PRESSURES
* = HARVESTER ALONE (NOT ATTATCHED TO TRACTOR)
TRAILER DRUMS
TRACTOR REAR, DOUBLE
TRACTOR FRONT, SINGLE
SCREW LEVELLER
TRACTOR FRONT, DOUBLE
S , KPa
CONTACT LENGTH , cm

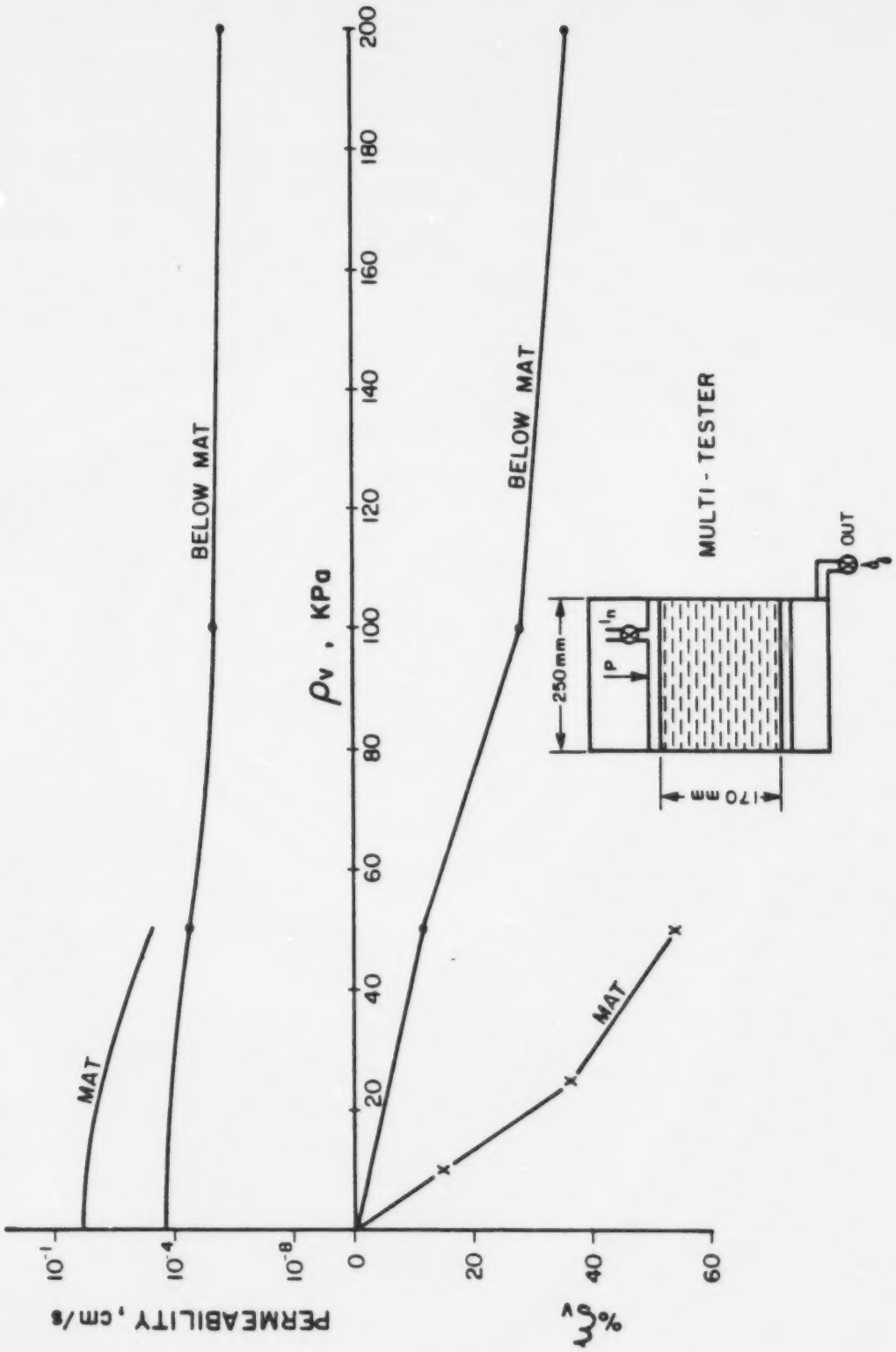

PERMEABILITY, cm/s
10^{-1}
10^{-4}
10^{-8}
MAT
BELOW MAT
ρ_v, KPa
0
20
40
60
80
100
120
140
160
180
200
BELOW MAT
MAT
ω_v %
0
20
40
60
MULTI - TESTER
OUT
250mm
170mm

Figure 15

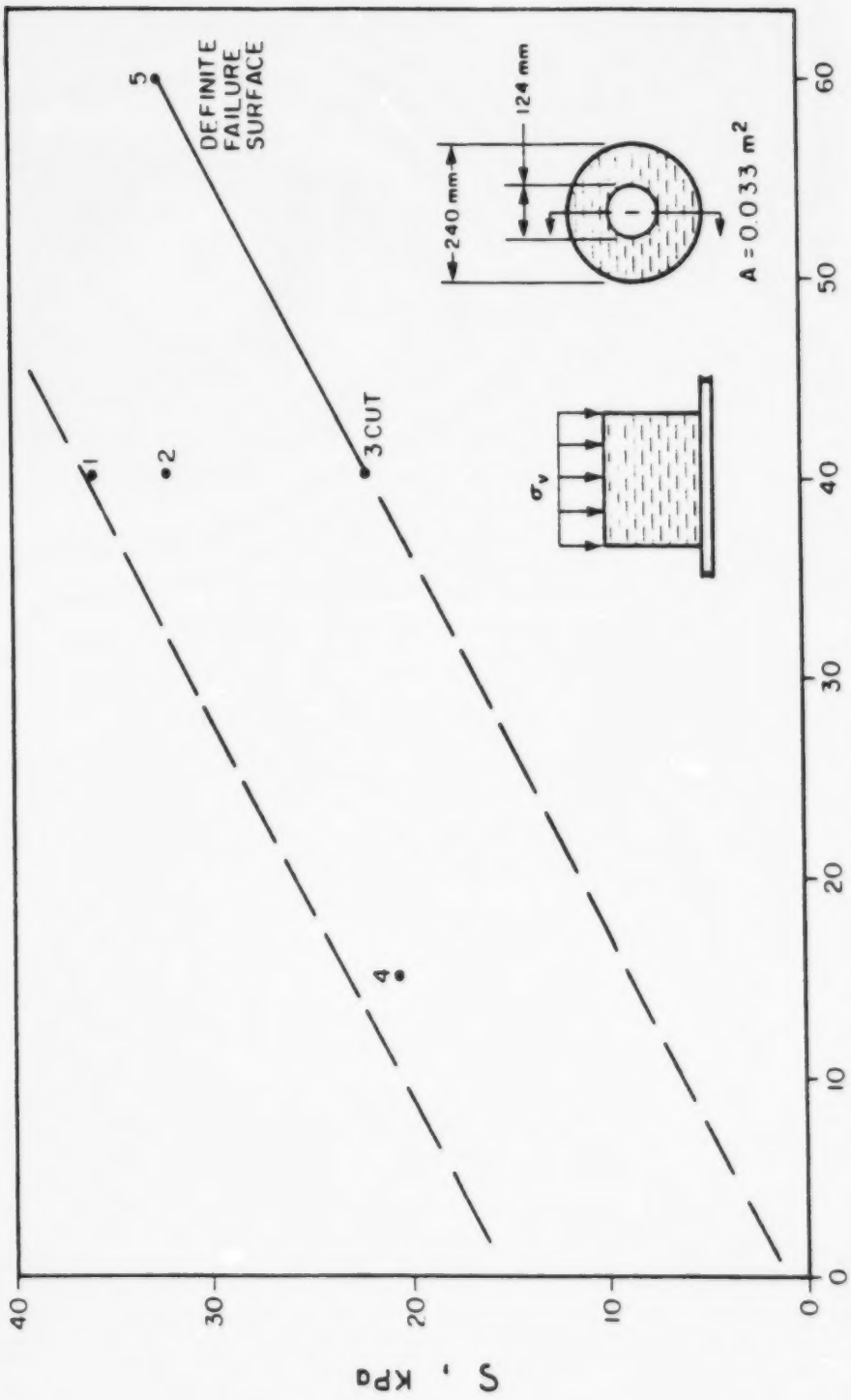
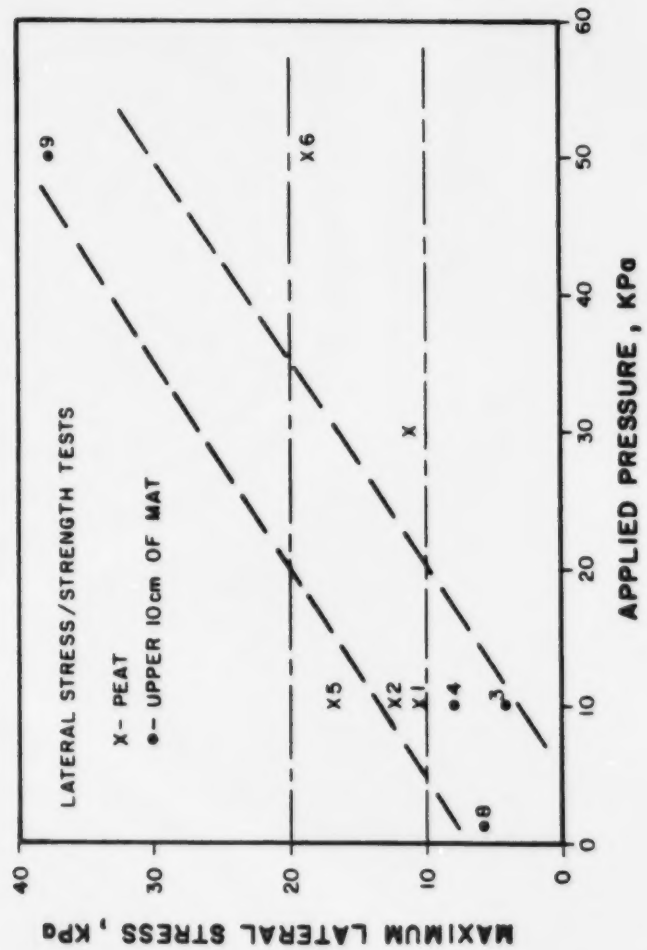


Figure 16
RING SHEAR TESTS

Figure 17a


LATERAL STRESS/STRENGTH TESTS
X- PEAT
•- UPPER 10cm OF MAT
X1
X2
X5
X
X6
•3
•4
•8
•9
MAXIMUM LATERAL STRESS, KPa
APPLIED PRESSURE, KPa
0
10
20
30
40
0
10
20
30
40
50
60

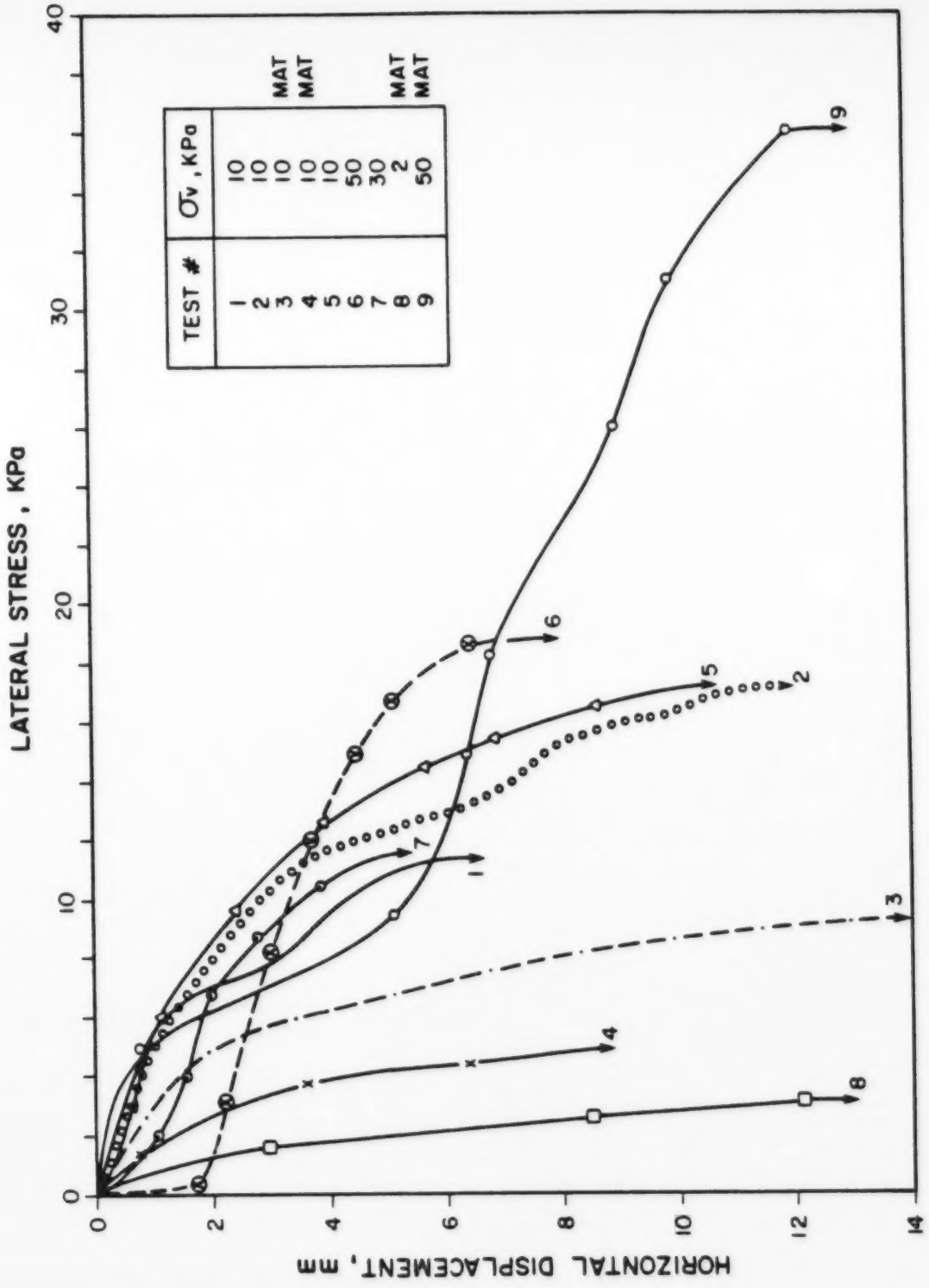
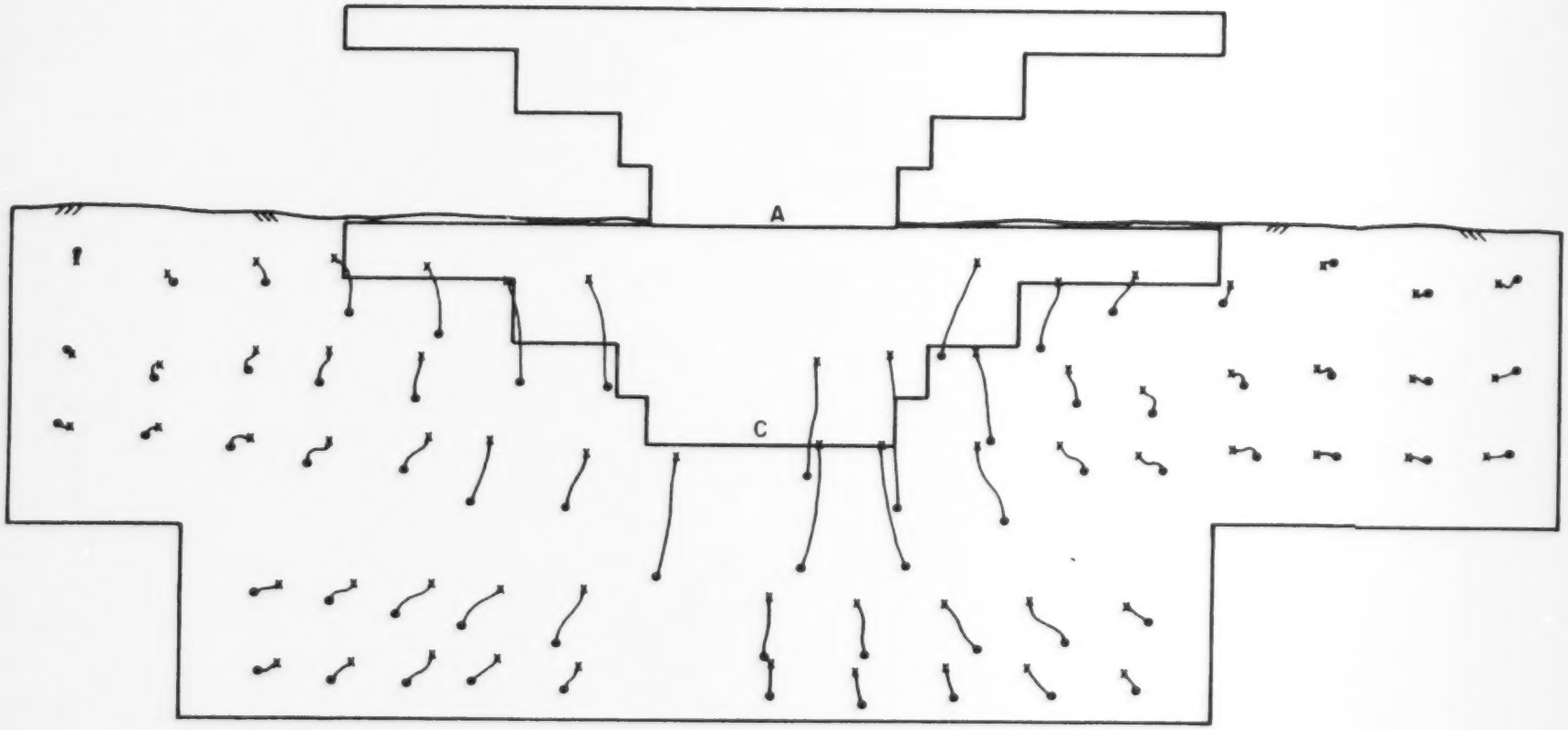

LATERAL STRESS, KPa
HORIZONTAL DISPLACEMENT, mm
0
10
20
30
40
0
2
4
6
8
10
12
14
TEST # | σv, KPa
1 | 10
2 | 10
3 | 10
4 | 10
5 | 10
6 | 50
7 | 30
8 | 2 MAT
9 | 50 MAT

Figure 17b

Figure 18a

MODEL TEST



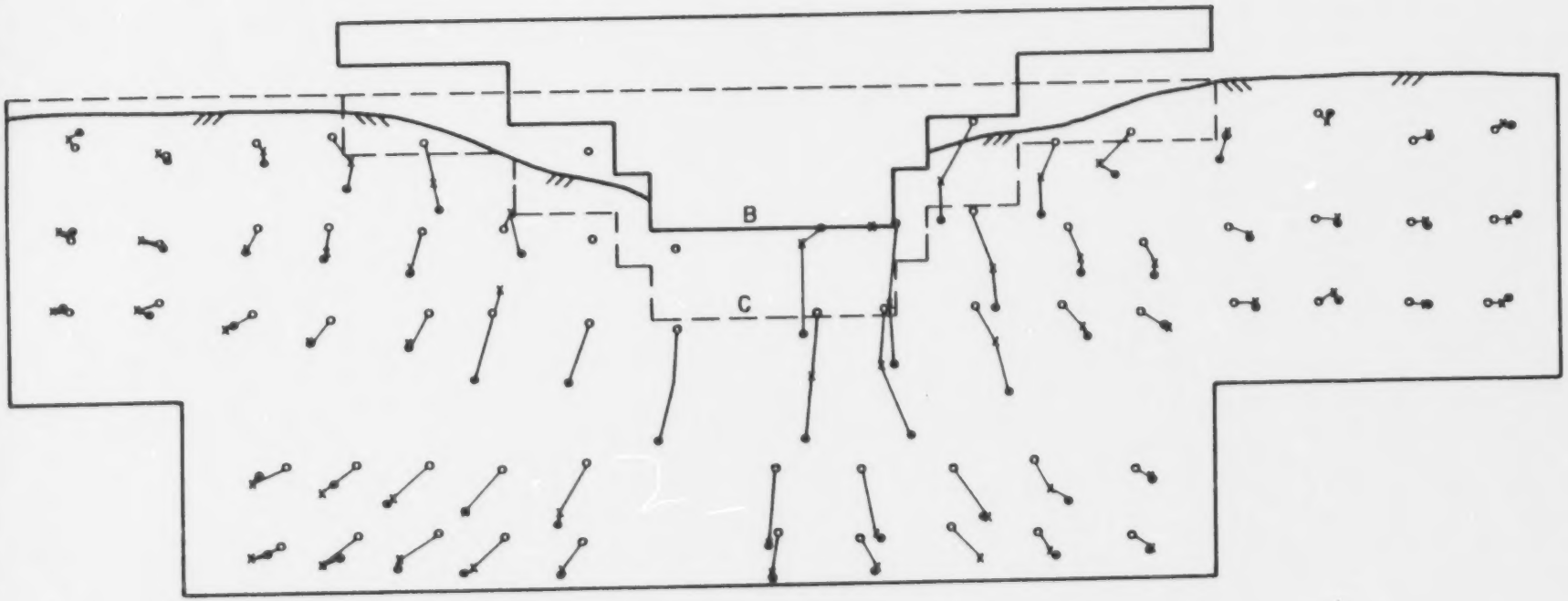
SCALE 1:5

OVERALL MOVEMENT OF PINS

x START
• END

Figure 18b

MODEL TEST



VERTICAL DISPLACEMENT = 10 cm

DISPLACEMENT TO FULL-LINE POSITION B

DISPLACEMENT FROM POSITION B TO POSITION C

APPENDIX 2

St. Shotts Peatland Drainage Project

Prepared for

Northland Associates Limited

September 1986

Monenco Peat Group
Monenco Consultants Limited
155 Rexdale Blvd.
Rexdale, Ontario
M9W 5Z8

LIST OF FIGURES

Figure 1. Collapsed perimeter ditch. Note the overhang and broken irregular edge of production field.

Figure 2. Field ditch too shallow and not maintained properly. Note accumulation of water.

Figure 3. Unmaintained field ditch. Note accumulation of water.

Figure 4. Unprepared field with the original vegetation in place impeding drainage and drying of sods.

Figure 5. Unprofiled fields and shallow ditches keep the groundwater table high.

Figure 6. Unprofiled field and a shallow ditch destroyed by traffic impede drainage.

Figure 7. Parallel continuous rows of sods hinder drainage and slow down drying.

Figure 8. Suggested drainage plan.

1.0 BACKGROUND

There is currently an ongoing attempt at St. Shotts to produce sod peat to be used as a fuel. However, after a number of years, great difficulties are still experienced in trying to harvest any significant quantities of peat at this site. It is apparent that both the weather and drainage conditions alone, and combined, create conditions that make it difficult to mine peat with conventional dry mining methods. In order to study the drainage parameters and possibilities of modifying them, Northland Associates Limited of St. John's, Newfoundland was contracted to carry out a drainage experiment and a monitoring program at the St. Shotts site. Monenco Consultants Limited was sub-contracted by Northland Associates to advise on the actual installation of the drainage system for this experiment. The following is a brief report on Monenco's findings and recommendations. It also contains a brief account of the state of the drainage at the existing peat production site with comments on its influence on productivity.

2.0 ST. SHOTTS PEAT PRODUCTION SITE

2.1 Introduction

The following comments are made to offer background for the proper drainage test performance so that the problems evident at the present site can be avoided.

2.2 Principal Objectives of Drainage for Peat Mining

The number one problem in peat mining is water. Peat in its natural state contains well over 90% water on wet weight basis. This high moisture content makes it unsuitable for many uses and also impassable by any heavy equipment. The first step in any plan to utilize peatland is to reduce its moisture content to a level that makes it possible to operate mining equipment on the bog surface and also enables drying of the peat on the surface after it has been either milled or turned into sods. Also, the low moisture content is required for sod production as at a moisture content higher than 84-86% the sods will not form properly. In order to attain this 84-86% moisture content for the surficial layer with a thickness of at least 30 cm, but preferably 70-80 cm, the bog has to be properly ditched and allowed to drain long enough (from one to several years depending on the site specific conditions).

2.3 Observations and Comments on St. Shotts' Drainage

Apart from extremely humid and unstable weather conditions that appear to make St. Shotts site unsuitable for peat production, the drainage of the site was at the time of visit (September 1986) basically non-functional. For the drainage to be effective, it is important that the ditches be deep enough and properly shaped to avoid collapse. No water is to be allowed to stagnate either in the ditches or in the fields, all culverts are to be open. The fields should be stripped of the living vegetation and, if possible, of the surficial layer of horticultural peat. The fields are to be profiled so that the centers are higher and there are no large depressions lengthwise and any hollows naturally occurring, or caused by equipment, must be either filled up with peat or drained individually into the present ditch.

At St. Shotts, the observation of the fields revealed the following problems with the drainage.

- The perimeter ditches were too shallow and their shape was improper. Rather than having been dug at least 2 m deep they were often only slightly over 1 m deep. Instead of being V-shaped, with sloping sides and a narrow flat bottom, they had been dug vertically into the peat. This allows the side walls to collapse into the ditch leaving the surficial peat hanging over and then later tumbling and sliding into the ditch, blocking it and also making the edge of the production field irregular (Figure 1).

- Field ditches also, in most cases, were too shallow, being only 70 cm deep. For the best efficiency, they should be about 1.3 m deep. Also, the ditches have to be properly maintained to ensure that they are not blocked by debris and loose in peat. Figure 2 is an example of the field ditch that is too shallow and has not been cleaned to ensure free flow of water. It is also an example of a recurring problem with a blocked ditch causing the water to back up in the ditch.

  Figure 3 is a typical view of a partially collapsed and unmaintained field ditch. As a result, the entire production field remains too wet for production activity.

- Fields were not prepared properly and the original vegetation was left on the surface (Figure 4). This traps water and does not allow either the lowering of the water table or drying of sods.

- Fields for the most part were not profiled allowing the rain water to accumulate on the surface and keeping the groundwater table high. Also, the addition of shallow groove-like ditches in the middle of unprofiled fields further collects water and holds the groundwater table high (figures 5 and 6).

- The sod cutter used lays continuous parallel rows of sods which limit the flow of surface water into the ditches. Also the drying of sods in parallel rows is slower than when they are spread in an irregular pattern on the ground (Figure 7). In areas, such as St. Shotts, with a high precipitation and cool humid climate, the diameter of sods must be small to ensure faster drying.

3.0 DRAINAGE EXPERIMENT

3.1 Introduction

In order to establish the proper drainage parameters locally for the St. Shotts peat production area and to get the drainage plan on a sound basis rather than a haphazard system presently used, a test area was selected to test different drainage plans. These plans include plots on which 5, 10 and 20 m ditch spacings will be assessed. In addition to the ditch spacing the effect of the surface preparation will also be assessed by leaving some fields unprepared while others will be properly stripped of their surface vegetation and profiled to give them the desired contour used in standard peat mining operations.

To assess the effectiveness of the drainage the weather data, groundwater table fluctuations and flow in the ditches will be monitored. The following is a concise description of the plan suggested for the drainage test.

3.2 Drainage Plan

Figure 8 is the suggested drainage plan for the project. The basic objectives of the drainage are to reduce the surface moisture content of the bog to about 84-86% and lower the water table to 30-80 cm from the surface. Once this is attained, the bog is firm enough to carry equipment and dry enough to allow good sod formation and drying of peat on the surface. The following describes the proposed plan.

3.2.1 Perimeter Ditches

Perimeter ditch is to be initially 1.4 to 1.6 m deep. Its base is to be 0.5 m wide and the slope ration 0.5 (see the diagram in Figure 8). It is suggested that, in the case of St. Shotts, the existing two small drainage channels be used as perimeter ditches. This would greatly reduce the costs and also would ensure a simple and more efficient drainage than if a separate ditch were excavated to parallel the channels. Also, the maintenance of the perimeter ditch would be minimal as the existing natural channels already have stabilized gently sloping banks. In fact, only minor cleaning of vegetation and peat would be required to improve them to the standards required of a perimeter ditch. As these channels have no importance as possible fish streams, nor do they exhibit any unique features in regard to their vegetation, their use as perimeter ditch would not cause any environmental damage. In any case, digging of a new parallel ditch along these channels would change their character totally since the drainage of the area would be drastically changed. Also, if this location is seriously considerably for peat industry, then the priority must be placed on the demands of the industry within the block of land allocated for it. This means that whatever drainage is needed must be performed in the most efficient manner to ensure the success of the operation. In this location, this means the total drainage of the area since it does not entail any unique or environmentally fragile features.

After about 6-7 months the perimeter ditch should be cleaned and, if needed, deepened to the depth of 2.2 to 2.4 m. However, at this location, where the maximum peat thickness is less than 2 m, no deepening may be required.

For sufficiently efficient drainage, the bottom gradient of the perimeter ditch should be a minimum of 0.002%. It is suggested that if a standard backhoe is used, the ditch be dug so wide at the top that the recommended side wall slope ratio of 0.5 is obtained (Figure 8).

Since the drainage system does not discharge into any sensitive receiving stream of lake, no sedimentation pond is required. The limited quantity of peat sediments that are released will for the most part get trapped by the lower reaches of the existing channels and in any case would not have any effect on the ocean water quality due to their minute quantity.

3.2.2 Field Ditches

The field ditches could be placed as recommended in Figure 8. Usually field ditches are placed at an angle against the gradient. This is done to ensure interception of downslope flow of water in the peat into the ditches faster than it would if allowed to flow along the gradient inside the peat in the middle of the fields. However, due to the limited size of the drainage area and the need to use the ditches for long enough fields, it is not possible to follow the optimum direction for the flow. It is felt that the suggested layout will give a representative effect for the St. Shotts production area.

The area is divided in three lots (Lots 1, 2 and 3). Lot number 1 is about 1 ha and consists of 12 fields 5 m in width. Lot number 2 covers about 2.7 ha and consists of 5 fields 20 m in width and Lot number 3 covers about 2.4 ha and consists of 10 fields 10 m in width.

Lot number 3 also contains a number of ponds. In order to separate their drainage from that of the test fields they have been interconnected with ditches, surrounded by a separate perimeter ditch and drained into the ditches bordering Lot number 3 (see Figure 8). In a normal operation they would be drained by field ditches and later used for peat production.

Due to the low thickness of peat at the test site the field ditches should be cut with the available Dondi ditcher to its optimum depth of 1.3 m. In a normal operation the first cut should be 1.0-1.2 m and the second one later 1.4 to 1.6 m with a 0.3 m bottom width and a 1.25-0.35 side wall slope ratio. The bottom gradient should be about 0.002% or slightly more. However, the availability of equipment and the size of the test area limits their dimensions to the limitation of the available equipment. The ditches should be cleaned in about 6 months time. If needed, the field ditches have to be cut into the underlying mineral soil to maintain their depth and bottom gradient.

3.2.3 Monitoring Program

The following monitoring program is suggested in addition to whatever monitoring the original contract signed by Northland Associates includes.

- The influence of the ditch spacing on water table.
- Influence of ditch cleaning and deepening on the water table.
- Subsidence of the test area during the drainage experiment (subsidence in the fields, bottom of ditches, etc.).
- Moisture content monitoring of peat in the surficial 30 cm layer.
- Water balance: variations in the seasonal flows, after precipitation events, after a number of years of drainage etc.
- The influence of the removal of the loose peat and vegetation from the surface on the drainage efficiency.
- The influence of the profiling of the fields on the drainage efficiency.

3.2.4 General Comments

- In order to run the test in a practical manner corresponding to normal industrial conditions it is suggested that the site be drained, e.g. in the fall of 1986, the ditches be cleaned and deepened in April-May 1987, and again in April-May of 1988. After this, during the late summer of 1988, a number of fields should be cleaned and profiled to bring them to industrial standards. The influence of this preparatory work and the drainage should be monitored until the end of 1989 with drying tests on sods on prepared and unprepared fields.
- In general, considering the low thickness of the peat and the extremely humid weather of St. Shotts, it appears that this site is not suitable for peat production in general.

- The failure until today is also largely caused by improper drainage of the site and the lack of site maintenance and field preparation and maintenance. This may be partly due to the lack of experienced personnel on the site.

- The usefulness of the drainage test program depends on:

a)sufficient time allowance (until the end of 1989).

b)use of experienced professionals in supervising the test.